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**Intermountain
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Experiment Station**

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Report INT-121

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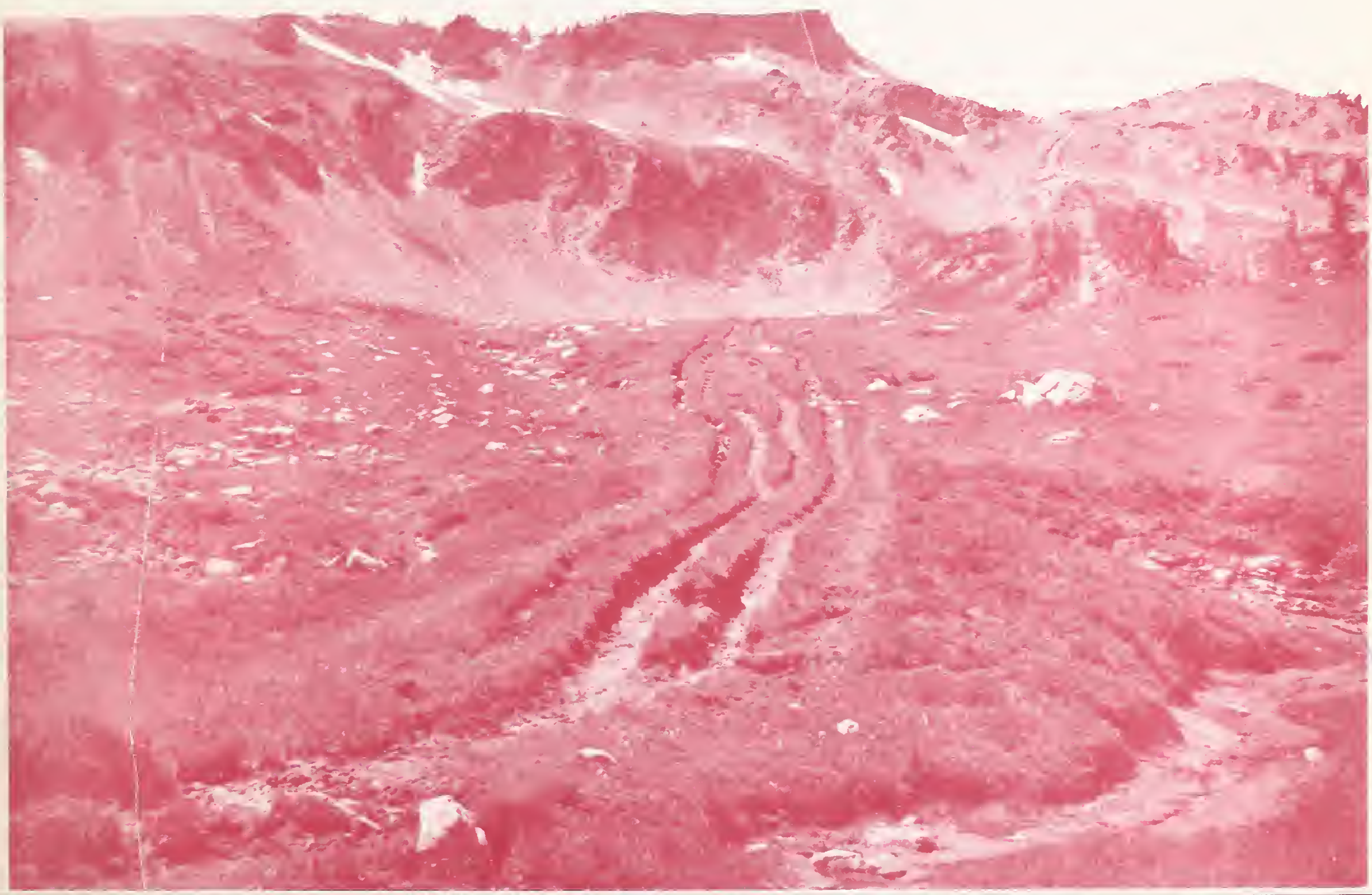
Impacts of Backcountry Recreation: Site Management and Rehabilitation — An Annotated Bibliography

David N. Cole and Edward G. S. Schreiner COMPILERS



THE AUTHORS

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RESEARCH SUMMARY

Management of wilderness and backcountry areas will profit from an increased understanding of recreational impacts and of how to respond to these impacts. Over 300 references on recreational impacts, impact management, and rehabilitation of impacted sites have been annotated in this bibliography. References have been indexed by location, subject, and plant species used for rehabilitation.

ACKNOWLEDGMENTS

We are indebted to numerous people for helping us with this bibliography. In particular, we would like to thank the following for help with compilation and valuable technical assistance: J. K. Agee, J. Aho, J. Dalle-Molle, J. Kailin, J. N. Long, J. Miller, M. Miller, B. Moorhead, P. R. Saunders, R. L. Scott, and L. E. Underhill.

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INTRODUCTION

Recreational use of backcountry areas has increased dramatically in recent decades. Associated with this increased use has been an increase in the severity and extent of human disturbances of these near-pristine areas. Land managers are understandably concerned about this situation because many of them have the responsibility of maintaining the quality of this recreational resource. This is particularly true for the areas in the National Wilderness Preservation System and the backcountry of National Parks where a major goal is to preserve "natural conditions."

In order to deal effectively with the problem of human disturbance in recreation and natural areas, managers need to understand recreational impacts in sufficient detail to determine how much and what kind of change is acceptable. Since very low levels of recreational use cause at least some deviation from absolutely natural conditions, the first task facing the manager is to define what Frissell and Stankey (1972) call the "limits of acceptable change," the maximum amount of deviation from natural conditions consistent with the management objectives of an area. Such decisions should take into account general management objectives, the significance of impacts both in terms of maintaining ecosystem processes and visitor satisfaction, and the practicality of confining impacts within the chosen limits. Once a decision on the limits of acceptable change has been made, the task becomes ensuring that the limits are not exceeded, and rehabilitating places where the limits have been surpassed.

Accomplishment of the above tasks requires both detailed understanding of ecological processes and their relationship to visitor use and impact, and practical methods for managing users and sites. Although a considerable body of literature on this subject does exist, there is no "cookbook" available for making decisions. Information on impact processes and management techniques is scattered in journals, theses, and unpublished reports. We believe that an interpretive bibliography on backcountry impacts, impact management, and rehabilitation would be particularly valuable at this time, even though portions of this literature appear in other bibliographies (Stankey and Lime 1973; Speight 1973; Steen and Berg 1975; Wall 1977).

Scope of the Bibilography

This bibliography is primarily concerned with recreational impacts on the soils and vegetation of backcountry areas and with how to rehabilitate sites that have received excessive impact. We have also included helpful references on backcountry management and techniques for minimizing impact. Recreational impacts on wildlife and water quality were considered to be beyond the scope of this bibliography, although the Intermountain Forest and Range Experiment Station has just completed a complementary bibliography, "Impact of backcountry recreationists on wildlife: an annotated bibliography" (Ream 1980).

Although the main concern of the bibilography is with backcountry areas, relatively few studies have been conducted in the backcountry. Consequently, we have included many studies undertaken in areas accessible by motor vehicles. Useful information can be derived from these studies, as long as differences in management objectives and type and amount of use are kept in mind. The same cautionary advice applies to our inclusion of revegetation studies on mine spoils or logging roads, where disturbance may be more extreme than that which occurs on recreation sites. The only sources that have been purposely left out are those we considered to be redundant, overly general, or not applicable. In the cases of the Rehabilitation and Related References sections, many marginally applicable references have been included.

The thoroughness of the bibliography was advanced by distributing copies of a preliminary bibliography to experts in the field, soliciting additional references. We are responsible, however, for the final selection of references and for omissions prior to October 1979. Cole has had primary responsibility for the impact and management section and Schreiner for the section on rehabilitation. In contrast to most other bibliographies, ease of access was not a significant selection criterion; many theses and unpublished documents are included because these often contain much relevant information. We were able to find copies of all references we annotated. Although we cannot provide a library loan service, all of these references are in the files of the Wilderness Management Research Unit, Intermountain Forest and Range Experiment Station, Missoula, Mont.

Organization and Content of Annotations

The contents of the bibliography are arranged in four parts: Recreational Impact, Impact Management, Rehabilitation of Impacts, and Related References. Each reference was assigned to the section we considered most applicable. If pertinent to other sections, it is identified by number at the beginning of the section and indexed under all relevant subjects. Within sections, citations are arranged alphabetically by author.

References in the Related References section do not deal directly with the subject matter of the bibliography, but contain information that may be usefully applied. For example, we have included several papers on both soil compaction of agricultural lands and seed germination of selected species. These papers are indexed under the appropriate section. A number of potentially interesting references, which were not located before October 1979, have been listed under nonannotated references. Selected references on water quality and off-road vehicle impacts have also been listed.

It was our intent to make the bibliography more than an access tool; we wanted it to report the major findings of each reference in sufficient detail so the reader might not always have to go to the reference itself. Thus, where references contained specific information related to particularly important mangement questions, we have tried to include this information. Subjects we attempted to highlight in this manner include: the ecological significance of documented impacts; the functional relationship between impacts and environmental and use characteristics; spatial and temporal patterns of impact; specific methods for minimizing impacts; and successful as well as potential methods of site rehabilitation. The choice of which results to highlight and the interpretations and evaluations of the references are based on our personal judgments.

Most of the references report the results of short-term case studies, done in one place at one time. This raises the question of how applicable the results are to other areas. We have dealt with this problem in two ways. First, we have provided a locational index, so that the reader can concentrate on references applicable to the geographic area or ecosystem type of interest. Second, we have included evaluative comments in many of the annotations in an attempt to address the general applicability and validity of the methods and results reported.

The Rehabilitation of Impacts includes a wide variety of papers from different sources. Other sources of information and assistance in rehabilitation projects may be locally available to the manager. Garden clubs, native plant societies, rock garden clubs, and local nurseries often have people with good knowledge of the local flora and specific knowledge concerning propagation of difficult species. Another source of information is the considerable body of literature on commercial reforestation techniques.

Fertilizers described in the Rehabilitation of Impacts section require some explanation. Numbers in parentheses are the standard method of listing fertilizers and refer to the percentage by weight of total nitrogen (N), available phosphorus (P_2O_5), and water soluble potassium (K_2O). Thus, 100 units (such as pounds or kilograms) of a 16-20-0 fertilizer contain 16 units of total N, 20 units of available P_2O_5, and 0 units of water soluble K_2O. Some studies refer to the number of kilograms per hectare of a specific element or compound, rather than the number of kilograms per hectare of fertilizer. In this case, any fertilizer meeting the specifics of the study could be used. Attention should be paid to the type of fertilizer used (such as urea, or ammonium phosphate). For example, some fertilizers use nitrate (NO_3) as the nitrogen component and others employ ammonium (NH_4). Exact replication of a treatment requires the same form of nitrogen as well as the same quantity.

Indexes: Key to Using the Bibliography

The index is divided into locational and subject matter indexes. The locational index is divided into a geographic index, which includes the country, State, National Park, Wilderness Area, or mountain range in which the research was conducted, and an ecosystem type index. The subject matter index is divided into recreational impact, impact management, and rehabilitation of impacts indexes. The rehabilitation of impacts index also includes a species index for persons interested in working with particular species or in finding out what has been done with species from their own area. The species index includes notations on what type of work (such as laboratory germination, or transplanting) has been done with each species and whether or not the species was introduced or native to the United States.

It is our hope that this bibliography will serve both the backcountry manager and the researcher. It should help make the manager aware of what work has been done in his area or subjects of concern. The cautionary advice and interpretations of the data should help avoid misapplication or placing too much faith in conclusions that are not supported by data. The bibliography also gives some idea of locations and subjects which need additional research. For example, by studying the index, one can see that little research has been conducted in the southwestern United States, except on the revegetation of mine spoils, and that we know little about differences in the impacts

caused by different types of use. The bibliography should, therefore, aid in the identification of research needs, as well as in facilitating the literature search of investigators.

PUBLICATIONS CITED

Frissell, S. S., and G. H. Stankey.
1972. Wilderness environmental quality: search for social and ecological harmony. *In* Proc. Soc. Am. For. p. 170-183.
Ream, C. H.
1980. Impact of backcountry recreationists on wildlife: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-81, 62 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Speight, M. C. D.
1973. Outdoor recreation and its ecological effects: a bibliography and review. Discuss. Pap. Conserv. 4, Univ. Coll., London, 35 p.
Stankey, G. H., and D. W. Lime.
1973. Recreational carrying capacity: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-3, 45 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Steen, O., and W. A. Berg.
1975. Bibliography pertinent to disturbance and rehabilitation of alpine and subalpine lands in the southern Rocky Mountains. Environ. Resour. Cent. Inf. Ser. 14, Colo. State Univ., Fort Collins, 104 p.
Wall, G.
1977. Impacts of outdoor recreation on the environment. Counc. Plann. Libr. Exch. Bibliogr. 1363, Monticello, Ill., 19 p.

RECREATIONAL IMPACT

(Also see reference numbers *150, 151, 153, 154, 162, 166, 172, 192, 198, 201, 260, 269, 272, and 279.*)

1. Aitchison, S. W.
1976. Campsite usage and impact. *In* An ecological survey of the riparian zone of the Colorado River between Lees Ferry and Grand Wash Cliffs. p. 155-172. S. W. Carothers and S. W. Aitchison, eds. Tech. Rep. 10, Natl. Park Serv., Grand Canyon Natl. Park, Ariz.

Amount of campsite use was compared to an index of human impact at 41 sites along the Colorado River. There was no relationship between amount of use and impact. Sensitivity of the campsite environment and the nature of camper activities were more significant determinants of impact.

2. Allcock, P. J.
1973. Treading of chalk grassland. J. Sports Turf Res. Inst. 49:21-28.

This study utilized experimental trampling, with an artificial "foot," which approximated the pressure exerted by a human. This "foot" was dropped 0, 2, 4, 6, 10, 15, and 30 times/week for 8 weeks. Percent biomass loss was significantly related to trampling intensity, but 70 to 80 percent of the maximum loss occurred with only 2 impacts/week. Although differences were not statistically significant, loss of biomass occurred more rapidly under moist conditions, bulk density increased with trampling intensity (rapidly at first and then more slowly), and this increase was more rapid under moist conditions. The variability of the results, indicated by the lack of statistical significance, appeared to result from differences in species composition and in soil texture.

3. Bates, G. H.
1935. The vegetation of footpaths, sidewalks, cart-tracks and gateways. J. Ecol. 23:470-487.

A pioneering work on trampling effects on vegetation, which examines the conspicuous vegetational gradient perpendicular to trails — from bare earth, through a short vegetation of trampling-resistant species, to natural vegetation. A discussion of the species and growth-forms which occupy these zones is provided. *Poa pratensis* is the species most indicative of heavy trampling. Treading and puddling (formation of an impermeable surficial crust when fine-textured soils are trampled when wet) are identified as the major causes of these changes in species composition and growth form. Experiments showed that increased soil compaction, by itself, was less significant. Plants sown in consolidated soil showed reduced growth, but consolidation after seedling establishment had little effect, except on shallow-rooted plants. Morphological characteristics which promote survival along paths include conduplicate stems, folded leaves, and buds located below the ground surface. This work provides a good introduction to the study of trampled vegetation.

4. Bayfield, N.
1971. Some effects of walking and skiing on vegetation at Cairngorm. *In* The scientific management of animal and plant communities for conservation. p. 469-485. E. Duffey and A. S. Watt, eds. Blackwell Sci. Publ., Oxford.

This paper reports the results of several observational and experimental studies of human impact near a ski area in Scotland. Simulated trampling of *Phleum pratense* stimulated growth at low levels of trampling, but caused extensive damage at higher levels. *Trichophorum caespitosum*, a graminoid, was found to be more tolerant of trampling than sphagnum moss, lichens, and *Calluna vulgaris* heath. More useful for techniques than applicable results.

5. Bayfield, N. G.
1973. Use and deterioration of some Scottish hill paths. J. Appl. Ecol. 10:635-644.

The relationship between deterioration of paths in Scotland and various site characteristics was studied. Path width increased with increasing path wetness, roughness, and steepness, and decreased as the surface adjacent to the path became increasingly rough. On a newly opened path, more damage occurred as hikers walked downhill as opposed to uphill. These findings have significance to designing and locating trails.

6. Bayfield, N. G., and B. S. Brookes.
1979. Effects of repeated use of an area of heather *Calluna vulgaris* (L.) Hull moor at Kindrogan, Scotland, for teaching purposes. Biol. Conserv. 16:31-41.

Trampling by botany students over an 8-year period reduced both the cover and height of *Calluna vulgaris*. In both cases, differences were greater between control and light-use (20 students/m^2/year) zones than between light- and severe-use (80 students/m^2/year) zones, however. Changes in species richness and composition were minor at all use levels.

7. Bell, K. L., and L. C. Bliss.

1973. Alpine disturbance studies: Olympic National Park, U.S.A. Biol. Conserv. 5:25-32.

This paper describes the effects of trampling and road-cut disturbance on some alpine plant communities in Olympic National Park. Experimental trampling in snowbank and stone stripe communities showed that both productivity and cover decreased with use. Although path development was inconspicuous at the lowest trampling intensity (15 passes/week for 4 weeks), this low level of use caused more than 50 percent of the total damage. The relatively moist snowbank community was damaged more rapidly, but it also recovered more rapidly. No obvious relationship existed between degree of recovery and trampling intensity. Lichens were particularly susceptible to damage. In addition, the low diversity and cover of vegetation on a 31-year-old road cut illustrates how slowly vegetation recovers in the alpine zone. The suggested implications are that use should either be restricted in number or concentrated on constructed paths.

8. Bogucki, D. J., J. L. Malanchuk, and T. E. Schenck.

1975. Impact of short-term camping on ground-level vegetation. J. Soil Water Conserv. 30:231-232.

The immediate effects of two nights of camping by 30 people were studied on a previously unused site in New York. The site was on shallow soils under an open *Pinus banksiana* (jack pine) forest. Bedrock and bare ground increased from 10 to 15 percent as a result of reduced blueberry-moss-lichen ground cover. This illustrates the significant effects of even a short stay by a large group.

9. Boomsma, J. J., and S. W. F. van der Ploeg.

1976. Effects of three-year experimental trampling on a dune valley. Part I: effects of trampling during one season. Working Pap. 68, Inst. Environ. Stud., Free Univ., Amsterdam, Neth., 34 p.

Changes in vegetation and invertebrate fauna were noted on experimentally trampled plots. Vegetation volume (plant cover times height) decreased as trampling intensity increased, but the differences between trampling treatments were less pronounced than the difference between controls and the lightest trampling treatment. The fauna became more active following trampling, but there were no pronounced changes in species density or composition. (Compare with Chappell and others [1971, reference *22*].) Water permeability of the soil decreased in proportion to the logarithm of trampling intensity. The paper contains numerous tables and ordination diagrams, but it is not possible to conclude much from the data presented.

10. Boorman, L. A., and R. M. Fuller.

1977. Studies on the impact of paths on the dune vegetation at Winterton, Norfolk, England. Biol. Conserv. 12:203-216.

An innovative study of recreational impact on dune vegetation, utilizing air photos, ground transects, and experimental trampling. The relative vulnerability of the various vegetation types was determined by the percentage of paths in each type which were worn to bare sand. This ranking is quantified by relating each type to the rough grass type, a moderately vulnerable type which was experimentally trampled. Some types were judged to be 30 to 40 times as vulnerable as others. Vegetation damage (reduction in sward height) was logarithmically related to number of tramples, with most of the damage occurring at low trampling levels. The validity of the results must be questioned due to the many assumptions made and the fact that the original relative estimates of vulnerability did not take use intensity into account. The approach is interesting, however, as is the general discussion of results.

11. Bratton, S. P., M. G. Hickler, and J. H. Graves.

1977. Trail and campground erosion survey for Great Smoky Mountains National Park. Part I. Introduction and methods. Part II. Patterns of overnight backcountry use and the condition of campsites. Part III. The condition of trails. Part IV. The description of individual trails. Manage. Rep. 16. Natl. Park Serv., Southeast Reg., 661 p.

This report describes the condition of backcountry trails and campsites in Great Smoky Mountains National Park. Inventory methods which managers of other areas might want to consider are described. Suggestions on how they could be improved are given, although there is no discussion of the limitations of the methods used. Campsites with the most intense damage were usually horse camps and creekside sites, while sites with the greatest amount of disturbed area were usually shelters, easy access points, and trail junctions. This suggests that **intensity** of damage is primarily a function of site factors and type of use, while **area** of damage is a function of number of users. Trail problems are more extensive in areas with heavy horse use, in spruce-fir forests and early successional vegetation, and on certain trail slopes and orientations. This suggests that trail problems are more a function of location, design, and type of use than amount of use. (Compare with Helgath [1975, reference *53*].) A wealth of data is presented but little interpretation is provided. The use data that are regressed against impact are for only the last 3 years. Nevertheless, this is one of the most extensive data sets collected and could provide some valuable conclusions beyond the site-specific observations provided.

12. Bratton, S. P., M. G. Hickler, and J. H. Graves.

1978. Visitor impact on backcountry campsites in the Great Smoky Mountains. Environ. Manage. 2:431-442.

This paper summarizes part of the research reported in Bratton and others (1977, reference *11*). It describes campsite conditions in relation to site factors, type of campsite, and amount of visitation. Management implications and alternatives are discussed.

13. Bratton, S. P., M. G. Hickler, and J. H. Graves.

1979. Trail erosion patterns in Great Smoky Mountains National Park. Environ. Manage. 3:431-445.

This paper summarizes part of the research reported in more detail in Bratton and others (1977, reference *11*). Trail erosion is related to forest type, geology, elevation, trail slope, section of the park, and amount of use. Water erosion is the major trail problem and may cause severe problems even on low-use trails. Trails oriented perpendicular to contours and with slopes greater than 10 degrees are consistently in poor condition.

14. Brew, N.

1976. Biological and sociological investigations of backcountry recreation: an annotated bibliography. Unpubl. rep., Natl. Park Serv., Grand Canyon Natl. Park, Ariz., 48 p.

This is a bibliography of short abstracts and 200 citations. The more important papers are also reviewed in the present effort, but we have made no effort to include sociological references.

15. Brockman, C. F.

1959. Ecological study of subalpine meadows, Paradise Valley Area, Mt. Rainier National Park, Washington. Unpubl. rep., Natl. Park Serv., Mt. Rainier Natl. Park, Wash. 83 p.

Used and unused parts of subalpine meadows in Mt. Rainier National Park are compared. The great enviornmental heterogeneity of these meadows means, however, that unused areas do not provide adequate controls and so specific results should be used cautiously. Both the desirability and the regenerative ability of these meadows were higher than expected. Species which were particularly resistant or sensitive to recreational use are noted. The study is mostly site specific in value.

16. Brockman, C. F.

1960. Ecological study of subalpine meadows, Yakima Park and Tipsoo Lake Area, Mt. Rainier National Park, Washington. Unpubl. rep., Natl. Park Serv., Mt. Rainier Natl. Park, Wash. 96 p.

Similar to Brockman (1959, reference *15*) in that a large amount of site-specific information is provided. Observations on species response to trampling may be generally useful.

17. Brockman, C. F.

1964. Investigation of damage at Tipsoo Lake and Mowich Lake, Mt. Rainier National Park, Washington. Unpubl. rep., Natl. Park Serv., Mt. Rainier Natl. Park, Wash. 72 p.

The average amount of denuded area around Tipsoo and Mowich Lakes was 10 and 24 percent respectively. Most of the devegetated area occurred on informal trails. Site-specific observations and recommendations are included.

18. Brown, J. H., Jr., S. P. Kalisz, and W. R. Wright.

1977. Effects of recreational use on forested sites. Environ. Geol. 1:425-431.

Recreational impact on the soils and vegetation of eight developed camp and picnic sites in mixed oak and white pine forests in southern Rhode Island were evaluated by comparing recreation sites with adjacent control plots. Soils on recreation sites had higher penetration resistance and bulk density and slower infiltration rates than controls. These changes were noted to a depth of 5 in (12.7 cm). On the less sandy soils, compaction resulted in less rapid soil water recharge and depletion and, therefore, less available water during the growing season. Exposed rock and bare ground increased as a result of the virtual elimination of the ground cover of tree seedlings, shrubs (Ericaceae) and herbs; grasses, lichens, and mosses increased in cover. Studies of radial and height growth of trees showed that although most trees grew normally on recreation sites, radial growth of *Pinus strobus* (white pine) and mean annual height growth of *Quercus coccinea* (scarlet oak) were reduced on recreation sites.

19. Bryan, R. B.

1977. The influence of soil properties on degradation of mountain hiking trails at Grövelsjön. Geograf. Ann. 59A(1-2):49-65.

Soil profiles were studied both on and off trails which receive estimated differences in amount of use. While the soil profiles on high-use trails were truncated more often than soils on low-use trails, particularly severe problems were associated with certain soil properties, regardless of amount of use. Trails in stone-free soils, with homogenous textures, were always deeply incised and trails in organic soils always became quagmires. Whether a certain soil property is advantageous or not depends upon many factors, however. For example, up to a certain threshold of trail degradation, an abundance of stones in the soil resists erosion; beyond this threshold, stones in the trail increase the turbulence of runoff down the trail and exacerbate the erosion problem. The discussion of these complex interactions and the detailed observations of the trail deterioration process make this a valuable reference for understanding trail impacts.

20. Buckhouse, J. C., G. B. Coltharp, and P. A. Barker.

1973. Impact of simulated recreation on soil compaction as modified by site and management techniques. Utah Acad. Sci. Proc. 50:17-24.

Describes the results of an experiment testing the effects of simulated trampling on soil compaction and vegetative growth. Control, trampled but unmanaged, and trampled and managed (fertilized and watered) plots were established in aspen and conifer forests in Utah. Trampling was simulated with a corrugated roller. After six seasons of trampling, soil penetration resistance had significantly increased in the aspen forests. There were no significant differences in amount of compaction between the two trampling treatments, but vegetative yield was greater on the managed plots. In the conifer forests, there was no significant increase in soil compaction on the trampled plots and no difference in vegetative yield between the trampling treatments.

21. Burden, R. F., and P. F. Randerson.

1972. Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. J. Appl. Ecol. 9:439-457.

This important paper reviews methods of studying the effects of human trampling on vegetation. It provides examples of short-term ecological changes resulting from greatly increased use and of the relationship between use and environmental conditions on sites which are presumably at equilibrium. Possible applications of various means of measuring use and statistical techniques for data analysis (correlation, ordination, and regression) are discussed. Species which were either sensitive or resistant to trampling are identified. Rosette plants increased and cushion and straggling plants decreased in response to trampling. As a group, grasses deceased at moderate trampling intensities and then increased and decreased again with further trampling. This paper is valuable as a summary of trampling research approaches and an introduction to some research techniques and results.

22. Chappell, H. G., J. F. Ainsworth, R. A. D. Cameron, and M. Redfern.

1971. The effect of trampling on a chalk grassland ecosystem. J. Appl. Ecol. 8:869-882.

Some effects of trampling on vegetation, on soil physical and chemical properties, and on soil fauna were measured in a chalk grassland in England. The amount of trampling was assessed on the basis of vegetation wear, a circular argument when subsequently relating this amount of trampling to vegetational characteristics. The discreteness of the three zones identified, however, provides some justification for this method. Plant and animal populations were reduced by trampling and species composition changed. No significant changes in soil chemical properties (pH, C/N ratio, ferrous-ferric iron ratio, and ammonium-nitrate balance) were detected, but there were significant changes in soil structure. With increased trampling,

soils were progressively compacted, in the surface 1 in (2.5 cm) only. Even more significantly, heavy trampling resulted in a serious loss of structural stability, a condition that leads to soil erosion.

23. Cole, D. N.

1977. Man's impact on wilderness vegetation: an example from Eagle Cap Wilderness, northeastern Oregon. Ph.D. diss. Univ. Oreg., Eugene. 307 p.

A survey of vegetation changes in Eagle Cap Wilderness resulting from the construction and use of trails and campsites, grazing by packstock, and fire suppression. The relative significance of each of these sources of change was evaluated, as was the relative susceptibility of different vegetation types to each source of change. In terms of areal significance, fire suppression was the most disruptive human activity in the wilderness, although recreational impacts were more intense in localized areas. Damage to vegetation along trails, in campsites, and in meadows grazed by packstock was often greater at lower elevations than in subalpine areas. This suggests that if maintenance of natural vegetation is a concern, appropriate fire management should be a top priority, and montane ecosystems should not be ignored just because impacts in the subalpine zone are often more visible. This dissertation is mostly site specific and observational in nature, but it does provide a broad overview of impact on vegetation.

24. Cole, D. N.

1978. Estimating the susceptibility of wildland vegetation to trailside alteration. J. Appl. Ecol. 15:281-286.

Vegetation change along wilderness trails can be measured by utilizing indexes of cover reduction and floristic dissimilarity. These indexes can be used to rank different vegetation types according to their susceptibility to vegetation change. In contrast to basing susceptibility estimates on changes resulting from experimental trampling, this method does not control amount of use as accurately, but it does incorporate more of the mechanisms of vegetation change (such as, changes in soil properties and changes associated with trail construction). In Eagle Cap Wilderness, Oreg., the understory vegetation of dense forests was more highly altered along trails than the understory of open forests and meadows.

25. Coombs, E. A. K.

1976. The impacts of camping on vegetation in the Bighorn Crags, Idaho Primitive Area. M.S. thesis. Univ. Idaho, Moscow. 63 p.

Ground cover conditions were measured on campsites which appeared to receive either light or heavy use. These sites were compared with adjacent control sites. As campsite use increased, bare ground increased and vegetation cover decreased, but the amount of organic litter remained constant. The number of species was abnormally high on light-use sites and low on heavy-use sites. Invader species, which contributed to the large number of species on light-use sites, were suggested as possible indicators of a deteriorating site. *Erigeron peregrinus* and *Antennaria lanata* are examples from the study area. This study is primarily site specific in value.

26. Crawford, A. K., and M. J. Liddle.

1977. The effect of trampling on neutral grassland. Biol. Conserv. 12:135-142.

Some effects of trampling on neutral (pH approximately 7.0) grassland were studied along the River Thames in England. Relative use was estimated with trampleometers (see Bayfield [1971, reference *151*]) during a study period of unspecified duration. Soil bulk density and penetration resistance increased initially with increased amounts of trampling, but remained relatively constant with additional trampling. Particularly resistant and susceptibile species are noted, but it is generally concluded that the trampling tolerance of a species cannot be divorced from the habitat in which it grows.

27. Dale, D. R.

1973. Effects of trail-use under forests in the Madison Range, Montana. M.S. thesis. Mont. State Univ., Bozeman. 96 p.

This thesis reports some of the results also presented in the more readily available article by Dale and Weaver (1974, reference *28*). It includes a stratification of trail width and trail depth measurements according to dominant overstory species, *Pinus contorta* (lodgepole pine), *Picea engelmannii-Abies lasiocarpa* (spruce-fir), and *Pinus albicaulis* (whitebark pine). The deepest trails were found in the spruce-fir forest, the most moist type, while the widest trails were found in the whitebark pine forest, the most open type. Trailside changes in the vegetation of each of these forests are also described and related to the effects of trampling and other environmental changes.

28. Dale, D., and T. Weaver.

1974. Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. J. Appl. Ecol. 11:767-772.

This paper discusses trail width and depth in relation to use and the composition of trailside vegetation in the Rocky Mountains of Montana. Trail width increased linearly with the log of user numbers but depth showed no consistent trend in relation to use. Trail widths in meadows were generally wider at high-use levels and narrower at low-use levels than trails in forests. Trails used by horses and hikers, as opposed to just hikers, were deeper and slightly narrower. This last result is contradicted by experimental results reported in Weaver and Dale (1978, reference *142*). Four responses of understory plants to the complex environmental gradient perpendicular to a trail are identified: increased presence along trails, decreased presence along trails, increased presence in the lightly disturbed part of the gradient, and no response to the gradient. Some of these responses are explained in terms of ecological changes along the trail and the narrowness of the disturbed zone along trails is stressed.

29. Davies, W.

1938. Vegetation of grass verges and other excessively trodden habitats. J. Ecol. 26:38-49.

This early description of plant communities which occur along roads and other heavily trampled locations in Great Britain illustrates the similarity of trodden vegetation in widespread localities. The most common survivors of heavy trampling were *Lolium perenne, Trifolium repens, Poa annua, Agrostis tenuis, Festuca ovina,* and *F. rubra.* This report is not highly appicable to the wilderness situation, but provides some insights into species resistance to trampling.

30. Dawson, J. O., D. W. Countryman, and R. R. Fittin.
1978. Soil and vegetative patterns in northeastern Iowa campgrounds. J. Soil Water Conserv. 33:39-41.

Comparison of neighboring sample plots in used and unused parts of campgrounds showed the following differences on the used sites: less soil macropore space, higher bulk density, higher pH, less soil organic matter, more grass cover, fewer plant species, less shrub cover, and more frequent crown dieback (on upland sites). Bottomland tree species, which naturally tolerate reduced soil aeration, apparently did not suffer from recreational use. Stand thinning and site hardening were suggested as means of reducing impacts.

31. Dawson, J. O., P. N. Hinz, and J. C. Gordon.
1974. Hiking trail impact on Iowa stream valley forest preserves. Iowa State J. Res. 48:329-337.

Soil and vegetative characteristics were measured, both on and along forested trails in Iowa. A dendrograph, based on similarity coefficients, suggested that more of the variability in ground cover composition resulted from natural site differences, either location of the study area or aspect, than from presence or absence of a trail. This is a surprising conclusion given the pronounced loss of cover, decrease in number of species, and increase in bulk density on trails which was also reported. Most of these changes were confined to 3 ft (1 m) on either side of the trail center. In addition, trails on north-facing slopes were less compacted and lost less ground cover than trails on flood plains or south-facing slopes. This may merely be a reflection of differences in amount of recreational use, however.

32. DeBenedetti, S. H., and D. J. Parsons.
1979. Mountain meadow management and research in Sequoia and Kings Canyon National Parks: a review and update. *In* Proc. Conf. on Sci. Res. in the Natl. Parks. p. 1305-1311. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5, Gov. Print. Off., Washington, D.C.

This paper provides a general survey of impact problems in mountain meadows and available management techniques, with particular emphasis on Sequoia and Kings Canyon National Parks. Vegetation alteration and erosion following trampling and grazing, trail problems specific to meadows, and invasion of meadows by trees are all discussed. The conclusion is that management techniques have significantly improved meadow conditions in recent decades.

33. Devos, A., and R. H. Bailey.
1970. The effect of logging and intensive camping on vegetation in Riding Mountain National Park. For. Chron. 46:49-55.

The effects of intensive use on the vegetation of developed campsites in *Populus tremuloides* (aspen) and *Picea glauca-Pinus banksiana* (white spruce-jack pine) forests in Canada are briefly discussed. Aspen mortality resulting from mutilations is considered to be the most serious alteration. Over one-third of the undergrowth species on campsites were exotics. Some management implications are provided in the article.

34. Dotzenko, A. D., N. T. Papamichos, and D. S. Romine.
1967. Effects of recreational use on soil and moisture conditions in Rocky Mountain National Park. J. Soil Water Conserv. 22:196-197.

This paper summarizes the results of a more detailed study by Papamichos (1966, reference *103*).

35. Douglas, G. W., J. A. S. Nagy, and G. W. Scotter.
1975. Effects of human and horse trampling on natural vegetation, Waterton Lakes National Park. Unpubl. rep., Can. Wildl. Serv., Edmonton, Alta, 129 p.

The experimental trampling plots of Nagy and Scotter (1974, reference *101*) were reexamined after 1 year of recovery. Two limitations of the study, the authors note, were that pretreatment measurements were not taken on all plots and that the sampling intensity was too low. After 1 year of recovery, results show that *Picea engelmannii* (Engelmann spruce), *Xerophyllum tenax* (beargrass), and *Abies lasiocarpa* (alpine fir) communities show little recovery after trampling, even at low intensities; *Dryas octopetala* (alpine dryad) and *Pinus contorta* (lodgepole pine) communities show some recovery, but are sensitive to moderate levels of trampling; and lowland sedge marsh, lowland and upland *Populus tremuloides* (aspen), prairie grassland, and subalpine mesic meadow communities are capable of recovering after 1 year, except under the heaviest use. Some plant communities, however, had very different responses depending upon the frequency and timing of the trampling and the measure of change employed (percent cover or standing crop). Interestingly, this fragility ranking is very different from that of Nagy and Scotter (1974) who considered only the rate of deterioration. The report includes a good data set.

36. Duffey, E.
1967. The biotic effects of public pressure on the environment. Monks Wood Exp. Stn., Symp. 3, Nat. Conservancy, Huntingdon, Eng.

These proceedings contain a number of early papers on recreational impact. Relevant papers include: "Public pressures on soils, plants and animals near ski lifts in the Cairngorms" by A. A. Watson; "Human pressures on the mountain environment of Snowdonia" by R. Goodier; "Changes in chalk grassland caused by galloping" by F. H. Perring; and "Human impact on the fauna, flora, and natural features of Gibraltar Point" by J. M. Schofield. Most of these papers are either general in nature or provide only preliminary research results. Consequently, they are primarily of historical interest.

37. Dykema, J. A.
1971. Ecological impact of camping upon the southern Sierra Nevada. Ph.D. diss. Univ. Calif. Los Angeles. 156 p.

This study assesses campsite conditions in the different life zones (Upper Sonoran, Transition, Canadian, Hudsonian, and Arctic-Alpine) in and near Sequoia National Park, Calif. The most consistent differences between controls and camps were increased soil compaction and decreased herbs, leaf litter, and deadwood on camps. Seedlings were less abundant on some camps and tree mutilation was greater on some camps, but there was no evidence of differences in tree canopy cover. The lower two life zones exhibited the greatest amount of change, with the Upper Sonoran camps having large decreases in seedlings and herbs and increases in tree mutilation and soil compaction and the Transition zone camps having large losses of deadwood, leaf litter, and duff. The Arctic-Alpine zone had a large decrease in herbaceous cover, while the Canadian and Hudsonian zones were the least affected by camping. Car camping and backcountry camping were not separated, however; so that amount and type of use differs between zones.

Moreover, differences are expressed in absolute rather than relative terms. Some of the higher elevation zones have more pronounced relative changes than the lower elevation zones, even though they receive less use than the lower zones.

38. Echelberger, H. E.
    1971. Vegetation changes at Adirondack campgrounds — 1964 to 1969. USDA For. Serv. Res. Note NE-142, 8 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Changes in campsite condition were measured over a 5-year period on developed campgrounds in the Adirondack Forest Reserve, N.Y. Use on the campgrounds ranged from 322 to 516 camper-days/tent site/year. Mean overstory density and vertical screening increased slightly, although there was considerable variability in the data. Lateral screening decreased slightly and 60 percent of the trees over 20 ft (6.1 m) tall were removed over the 5-year period. Deterioration and amount of use appeared to be unrelated. The conclusion was that well-maintained, developed campsites should not deteriorate much with continued use.

39. Emanuelsson, U.
    1979. A method for measuring trampling effects on vegetation ("the circle sector method"). *In* The use of ecological variables in environmental monitoring. p. 91-94. Natl. Swed. Environ. Prot. Board, Rep. PM 1151.

This paper outlines an efficient design for experimental trampling studies. It also shows that heath vegetation is more susceptible to trampling damage than meadow vegetation.

40. Faliński, J. B.
    1975. Die Reaktion der Waldbodenvegetation auf Trittwirkung im Lichte experimenteller Forschungen. [The reaction of forest ground cover to trampling in the light of experimental research.] Phytocoenologia 2:451-465. [In German, English summary.]

Experimental trampling was applied in an oak-linden-hornbeam forest and a continental pine-oak forest in Bialowieza National Park, Poland. Results include: more vegetation was lost during the second year of trampling than the first; luxuriant ground vegetation suffered greater losses (both absolute and relative) than sparse vegetation; the herb layer in the oak-linden-hornbeam forest disappeared more rapidly than that in the pine-oak forest, but it also recovered more rapidly; and bryophytes increased in biomass with trampling. This last conclusion contrasts with most reports.

41. Fenn, D. B., G. J. Gogue, and R. E. Burge.
    1976. Effects of campfires on soil properties. Natl. Park Serv. Ecol. Serv. Bull. 5, 16 p. Washington, D.C.

Campfires altered organic matter to a depth of 4 in (10 cm) (90 percent loss in the 0- to 1-in zone) and often created a water repellent layer about 1 in (2.5 cm) below the surface. These effects are reduced under moist conditions, on fine-textured soils, and when softwoods are burned. The authors suggest concentrating all campfires in one place on each campsite, rather than moving them around.

42. Foin, T. C., Jr., ed.
    1977. Visitor impacts on national parks: the Yosemite ecological impact study. Univ. Calif., Davis. Inst. Ecol., Publ. 10, 99 p.

This study of visitor use effects on some ecosystems in Yosemite National Park is most useful for research methods and for philosophical discussion of research approaches in relation to management policy. Specific results describe: vegetation change along meadow trails, with an increase in the prominence of some graminoids in heavily trampled zones; vegetation change in camps, where loss of ground cover, seedlings, and saplings was most important; and changes in bird and small mammal populations. More general conclusions were: trail formation in meadows occurs rapidly, but further deterioration is minimized because visitors stay principally on the trails; forested areas used for camping have been more seriously disturbed than meadows; and both comparative analysis and experimental research techniques are needed. (See Liddle [1975, reference *80*].)

43. Foin, T. C., Jr., E. O. Garton, C. W. Bowen, and others.
    1977. Quantitative studies of visitor impacts on environments of Yosemite National Park, Calif., and their implications for park management policy. J. Environ. Manage. 5:1-22.

Republication of the most substantive chapter of Foin (1977, reference *42*).

44. Frissell, S. S.
    1973. The impact of wilderness visitors on natural ecosystems. Unpubl. rep., 60 p. USDA For. Serv., For. Sci. Lab., Missoula, Mont.

This paper describes the condition of campsites in the Spanish Peaks Primitive Area, Mont. It includes a subjective site condition rating system based on a probable sequence of changes resulting from recreational use. Management prescriptions are provided for each condition class. The horse sites examined were 10 times larger than the hiker-only sites. They also had seven times as much exposed bare ground and had a median condition class of 4, as opposed to 2 for hiker camps (deterioration increases with increasing values up to 5). Camp size was not strongly correlated with condition class. The paper also contains a good discussion of research needs and an extensive bibliography.

45. Frissell, S. S., Jr., and D. P. Duncan.
    1965. Campsite preference and deterioration in the Quetico-Superior canoe country. J. For. 63:256-260.

Campsite condition was evaluated on selected sites in the Boundary Waters Canoe Area, Minn. Campsites, in comparison with adjacent controls, lost an average of 85 percent of their original ground cover, 65 percent of the litter and humus layers, and all of their tree reproduction. Increases in root exposure and soil compaction were also noted. Most of these changes occurred with only light use (0 to 30 parties/season); further increases in use caused relatively insignificant additional change. This suggests that reducing use will do little to improve campsite conditions, while shifting use to unimpacted sites will cause significant change. Use was determined on the basis of personal observations and the opinions of local guides.

46. Gibbens, R. P., and H. F. Heady.
1964. The influence of modern man on the vegetation of Yosemite Valley. Calif. Agric. Exp. Stn. Ext. Serv. Man. 36, 44 p.

This report describes vegetation changes in Yosemite Valley resulting from human activities. It deals primarily with activities other than recreational use, but it does briefly discuss soil compaction and loss of vegetation, litter, and duff in heavily trampled areas.

47. Goldsmith, F. B.
1974. Ecological effects of visitors in the countryside. *In* Conservation in practice. p. 217-232. A. Warren and F. B. Goldsmith, eds. John Wiley and Sons, London.

This chapter provides a thoughtful discussion of problems with impact studies and a summary of basic results. It advances some ideas about what determines the sensitivity of ecosystems to recreational pressure. It is highly general.

48. Goldsmith, F. B., R. J. C. Munton, and A. Warren.
1970. The impact of recreation on the ecology and amenity of seminatural areas: methods of investigation used in the Isles of Scilly. Biol. J. Linn. Soc. 2:287-306.

This methodological paper discusses an investigation of recreational visitors' activities and impacts on the vegetation of the Isles of Scilly. Both large-scale mapping techniques and transects were utilized. Vegetation maps were compared to visitor distribution data obtained from questionnaire-maps. This revealed the vegetational preferences of visitors. By using partial coefficients to reduce the effects of environmental variability, detailed transect data showed that increased trampling leads to reductions in the cover of most plants, the maximum height of the vegetation, and the number of species in flower. The results are of limited applicability, because only 1 week of field work was involved, but a number of potentially useful methods are suggested.

49. Hartesveldt, R. J.
1965. An investigation of the effect of direct human impact and of advanced plant succession on *Sequoia gigantea* in Sequoia and Kings Canyon National Parks, California. Unpubl. rep., Natl. Park Serv., San Francisco. 82 p.

Reported here are some results of a study completed in 1963 for the University of Michigan, which is described in more detail in a dissertation by the author. Soil compaction was found to a depth of 8 in (20 cm), although it was greatest in the upper 2 in (5 cm). Growth rates of *Sequoiadendron giganteum* (giant sequoia) were *greater* on compacted areas than on noncompacted areas. This appeared to result from increased soil moisture and reduced understory competition in the compacted zone. Although not inhibitive to tree growth, this compaction may inhibit root growth by other species, and it creates unfavorable conditions for seed germination and seedling establishment.

50. Hartley, E. A.
1976. Man's effects on the stability of alpine and subalpine vegetation in Glacier National Park, Montana. Ph.D. diss. Duke Univ., Durham, N.C. 258 p.

A good detailed study of human impact on subalpine and alpine vegetation near Logan Pass in Glacier National Park, Mont. Studies along existing trails and experimental trampling at various intensities are included. Major findings include: trailside vegetation has fewer species, fewer "rare" species, less total cover, and less total flower production than adjacent undisturbed vegetation; the mean distance from trail center to natural vegetation is 9.8 ± 6.6 ft (3 ± 2 m); in experimental trampling, 15 tramples removed almost as much cover as 50 tramples, although recovery was slower in the latter case; little long-term damage occurs if meadows are trampled less than 5 times/week; cover loss was more rapid and recovery took longer in dry meadows than in wet meadows; and less utilizable carbohydrate in the roots of plants near trails suggests this may be a consequence of trampling and helps explain reductions in plant height, cover, and flower density. A sensitivity index based on each species' ability to grow near trails is provided. Related soil changes, primarily in bulk density and soil compaction, are also discussed. The author presents a wealth of data, collected over a period of 6 years, and makes some attempts at generalization. Additional interpretation is possible.

51. Hartley, E.
1979. Visitor impact on subalpine meadow vegetation in Glacier National Park, Montana. *In* Proc. Conf. on Sci. Res. in the Natl. Parks. p. 1279-1286. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5. Gov. Print. Off., Washington, D.C.

Summary of research presented in more detail in Hartley (1976, reference *50*).

52. Hecht, S. B.
1976. Ecological carrying capacity research, Yosemite National Park. Part II. Human impact on subalpine ecosystems: microclimate. 27 p. U.S. Dep. Commerce, Natl. Tech. Inf. Cent. PB-270-956.

Microclimatic measurements, both on and off meadow paths, were taken in August. In all cases, ground and vegetation temperatures were higher and relative humidity was lower on paths. The percent decrease in relative humidity was greatest on paths in xeric meadows. There were no significant differences in percent increase in mean temperature between the five meadow types. Yet, the authors conclude that mesic meadows are the most highly altered in terms of microclimate.

53. Helgath, S. F.
1975. Trail deterioration in the Selway-Bitterroot Wilderness. USDA For. Serv. Res. Note INT-193, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This study reports on how amounts of trail erosion in the Selway-Bitterroot Wilderness, Idaho, vary with site conditions and amount of use. The three major types of trail problems encountered were entrenchment by erosion, bog formation on perched or high water tables, and landslides on oversteepened slopes. Amount of trail erosion, measured as cross-sectional loss below a taut tape, was found to be highly related to vegetation type, landform, and trail slope. Aspect, elevation, parent material, and amount of use were not related to amount of erosion in any consistent way. Results should be applied with caution, however, because the cross-sectional area of a trail tread is highly dependent upon side slope and trail construction

practices, in addition to erosion. Management implications for various combinations of landform and vegetation type (biophysical units) are provided. The publication emphasizes that these locational implications and the lack of correlation between use and amount of erosion are significant.

54. Hinds, T. E.
1976. Aspen mortality in Rocky Mountain campgrounds. USDA For. Serv. Res. Pap. RM-164, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Populus tremuloides (aspen) was found to be highly susceptible to canker diseases following mechanical injuries caused by campers. On the 17 campgrounds studied, trees were dying at a rate of 3.6 ± 1.0 percent/year. The author concludes that camping areas should not be located in aspen groves, if an enduring forest cover is desired.

55. Hoffman, M. K.
1975. Quantification of vegetational change concomitant with recreational use. M.S. thesis. Univ. Guelph, Ont.

Most of this thesis deals with vegetation classification of Rushing River Park. Vegetative cover was measured on 41 campsites. It was concluded that *Populus tremuloides* (aspen) stands were more resistant to campsite impacts that *Pinus banksiana* (jack pine) stands. This thesis represents one part of the study reported in James and others (1979, reference *59*).

56. Holmes, D. O., and H. E. M. Dobson.
1976. Ecological carrying capacity research: Yosemite National Park. Part I. The effects of human trampling and urine on subalpine vegetation, a survey of past and present backcountry use, and the ecological carrying capacity of wilderness. U.S. Dep. Commerce, Natl. Tech. Inf. Cent. PB-270-955, 247 p.

This report discusses many issues related to backcountry impact. The authors conclude that human urine does not create significant problems. The most important section of the paper discusses the detailed results of experimental trampling. Each species trampled was assigned both a survival rate and a recovery rate. Separate survival rates were provided for different seasons of trampling. Other factors which influenced survival rates were soil, topography, and plant community structure and composition. For example, survival rates of the same species were generally about three times greater in mixed communities than in pure stands. Growth habitat and tissue strength were the vegetative characteristics which appeared to influence survival rates most. Herbaceous plants with basal leaves were the most resistant to trampling, while plants with woody parts and tall, herbaceous, caulescent plants were the most susceptible. Moist areas recovered the most rapidly and the species which recovered most rapidly were those with regenerative buds at or below the surface. A final section relates these experimental results to carrying capacity and management alternatives.

57. Hudson, M.
1977. Fortymile River: biological aspects of carrying capacity. Unpubl. rep. U.S. Dep. Interior, Bur. Land Manage., Tok, Alaska. 52 p.

Four study sites in tundra were each trampled a total of 50, 250, and 1,000 times in one summer season. Trails usually were visible after as few as five tramples, while 100 tramples gave the sites the appearance of "irreversible damage." Lichens and mosses were particularly susceptible. Path width and depth increased and annual production decreased as the number of tramples increased. Three subsequent studies, with continued trampling and recovery of these plots, have been undertaken. On some sites, visual recovery of the 1000x plots was complete after 1 year; on other sites, the 50x plots recovered less than 10 percent. Well-drained sites without much moss and lichen appeared to be most resistant to use. These reports contain a great amount of data but little interpretation. The rapid recovery on some of the heavily-trampled plots suggest that the oft-mentioned fragility of the tundra is an overgeneralization.

58. Ittner, R., D. R. Potter, J. K. Agee, and S. Anschell, eds.
1979. Recreational impact on wildlands [Conf. Proc., Oct. 27-29, 1978]. USDA For. Serv., Pac. Northwest Reg., R-6-001-1979, 333 p. Portland, Oreg.

Proceedings for this conference were available after the literature search for this bibliography was completed so no attempt has been made to review individual papers. There are several papers, however, pertinent to both impact and rehab ilitation in the backcountry. Topics include vegetation and soil restoration, impact prediction, methods of preventing impact, educating the visitor, and visitor perceptions of impact and rehabilitation. This is a good source of information.

59. James, T. D. W., D. W. Smith, E. E. Mackintosh, and others.
1979. Effects of camping recreation on soil, jack pine, and understory vegetation in a northwestern Ontario park. For. Sci. 25:333-349.

In comparison to undisturbed areas, developed campsites had greater penetration resistance, more frequent tree root exposure and damage to tree stems, thinner horizons, slower infiltration rates, reduced tree diameter and tree foliage growth, and dissimilar understory composition. When low- and high-use campsites were compared, the only pronounced differences were in penetration resistance, number of exposed roots, and trunk scars. Infiltration rates on campsites were only one-twentieth of those in the undisturbed areas, but there was little differences between low- and high-use sites. This is interesting because infiltration rates are probably one of the most important soil changes on campsites. Changes in understory vegetation included invasion of weedy exotic species, loss of fleshy species and lichens, height reduction, and loss of many shrubs and young trees. These changes became relatively unimportant more than 16.4 ft (5 m) from the bare central part of the campsite.

60. Johnson, D. W., and T. E. Hinds.
1977. Aspen mortality at the Maroon Lake Campground. Biological Evaluation R2-77-21. 18 p. For. Insect Dis. Manage., State Priv. For., USDA For. Serv., Lakewood, Colo.

Populus tremuloides (aspen) are dying at an accelerating rate in this popular campground in Colorado. Photographs and stand data are provided, as are some suggestions on how to slow the deterioration process and possibly to rehabilitate the site. (See Hinds [1976, reference *54*] for more discussion.)

61. Jones, D. H.

1978. The effect of pedestrian impact on selected soils. M.S. thesis. Univ. Glasgow, Scotland. 154 p.

This is a detailed experimental study of the effects of trampling on two coarse soils in Scotland. Experiments included: a one-time trampling at six intensity levels (16, 32, 64, 128, 256, and 512 passes) on both soils at four different moisture levels; weekly trampling at rates of 64 and 256 passes/week for 12 weeks; and 10 weeks of recovery after a one-time application of 64 and 256 passes. Physical properties measured were soil moisture content, surface configuration, resistance to torque, resistance to penetration, bulk density, and moisture release characteristics (a measure of macropore volume). Soil moisture often influenced the magnitude of changes in these properties to a greater extent than amount of trampling. The most significant effects of increased trampling were increases in path depth, soil resistance to torque and penetration, and decreases in the volume of macropores. Most of these changes occurred at low trampling intensities, by 64 to 128 passes, and during the first few weeks of the 12-week experiment. Recovery, however, was minimal after 10 weeks. The author stresses the significance of the rapid loss of over 50 percent of the macropores, which greatly reduces the movement of water and air. This loss is much greater where trampling occurs when the soil is moist. He suggests that closure for natural regeneration is not a viable alternative because of the rapid degradation and slow recovery and that, in certain cases, questioning how much use is appropriate has little value, because any use causes most of the damage. This study includes a good literature review, discussion of methods, and suggestions for further research.

62. Kalisz, S. P., and J. H. Brown, Jr.

1976. Starch content of oak roots on campsites. Sci. Biol. J. (July-August): 160-165.

Starch levels in roots of oak trees (*Quercus alba, Q. velutina,* and *Q. coccinea*) were measured on and off campsites in Rhode Island. Only *Q. coccinea* showed any differences between campsites and control sites. It exhibited lower levels of starch on campsites, but only during a dry year. This was also the only species that showed reduced annual height growth on campsites. There were no apparent reductions in diameter growth. This suggests that campsite use has little effect on tree growth, except in the case of *Q. coccinea.* The authors note that more work is needed before any definite conclusions can be drawn.

63. Kazanskaya, N. S.

1977. Forests near Moscow as territories of mass recreation and tourism. Urban Ecol. 2:371-395.

The process of "forest retrogression" as a result of recreation use in forest stands near Moscow, USSR, is described. Increases in soil density, decreases in water permeability and litter, changes in the composition of the herbaceous layer, and loss of both young and mature trees are documented. Five stages of retrogression were identified, with the loss of regenerative ability under constant recreational pressure occurring between stages III and IV. Using this as the limit of permissible recreational pressure, birch and oak forests are shown to have higher recreational capacities than spruce forests. Seminatural "dense forest-clearing" complexes can absorb heavy recreational use. An interesting attempt to provide a rational basis for ecological carrying capacity determinations.

64. Kellomäki, S.

1973. Tallaamisen vaikutus mustikkatyypin kuusikon pintakasvillisuuteen. [Ground cover response to trampling in a spruce stand of Myrtillus type.] Silva Fenn. 7:96-113.

This paper describes the effects of simulated trampling, with a mechanical tamp, on the ground cover of a *Picea abies-Vaccinium myrtillus* (spruce-blueberry) forest in Finland. Tamping rates were 0, 1, 4, 16, and 64 tamps/plot/week, for 8 weeks. Forb cover was destoryed more rapidly than that of dwarf shrubs or grasses. Even slight trampling caused noticeable changes, with the most dramatic increases in cover loss occurring between 1 and 4 tamps/week and between 16 and 64 tamps/week.

65. Kellomäki, S.

1977. Deterioration of forest ground cover during trampling. Silva Fenn. 11:153-161.

Experimental trampling, at rates of 0, 4, 16, 32, and 64 tamps/week, for 7 weeks, was applied in three coniferous forests and a meadow in Finland. Decay function curves of biomass loss are provided, although from the description in the text, it appears that the figure captions have been misplaced. Rate of deterioration was most rapid on the infertile *Calluna* site type, primarily because of the fragile lichen layers present. In the meadow, 50 percent of the cover was lost almost as rapidly as in the forest (5-10 tamps/week). In the meadow, the equilibrium level, at which further trampling causes no additional deterioration, occurs between 60 and 70 percent biomass loss, compared to between 80 and 90 percent loss in the forests. The author argues that this superior ability of the grass-herb meadow to tolerate trampling may become even more pronounced with longer term trampling due to the ability of secondary vegetation to invade meadows. The suggestion is that the vegetation on fertile sites and meadows is especially tolerant of trampling.

66. Kellomäki, S., and V. L. Saastamoinen.

1975. Trampling tolerance of forest vegetation. Acta For. Fenn. 147:5-19.

Simulated trampling, using a mechanical tamp, was applied to five different vegetation types (three coniferous forests and two grasslands) in Finland. A trampling tolerance level was then assigned to each plant community and major plant species based on the rate that cover and biomass are removed as trampling increases. Lichens were particularly susceptible to trampling, as were dry sites compared to moist sites. In the coniferous forests, the moderately fertile site was more tolerant than the highly fertile site, which was more tolerant than the site with low fertility. Camping in meadows is considered to be the best solution to minimizing long-term damage, because resistant species invade meadows as trampling continues. An interesting approach, but the use of simulated trampling and the mathematical assumptions should make one cautious of directly applying the results.

67. Ketchledge, E. H., and R. E. Leonard.

1970. The impact of man on the Adirondack high country. The Conservationist 25(2):14-18.

This paper describes trail erosion and the destruction of alpine communities in the Adirondack Mountains of New York. Four stages of trail erosion are identified and measurements indicate that many trails are increasing in both width and depth at a rate of 1 inch/year (2.5 cm/yr). The authors briefly describe experiments designed to determine possible means of supplementing the deteriorated sphagnum moss tundra found on mountaintops with more trampling-tolerant nonnative species. They report 70 to 90 percent success with seeding grasses, where fertilizer is applied concurrently.

68. Kregosky, B., E. Nowick, D. Parsons, C. Watson, and F. Marsh.
    1972. Great Divide Trail survey, 1971; an ecological investigation of the proposed route. (Two vols.) Unpubl. rep., Can. Wildl. Serv., Edmonton, Alta.

This survey of existing and potential impacts along the Great Divide Trail in the southern Canadian Rockies is mostly site specific, but it provides some general information on site conditions that contribute to trail deterioration problems. The most severe problems were found in areas with poorly drained soils. Other problems were found in areas of late snowmelt, on talus slopes with active downslope movement, and where trails climb streambanks vertically. The soils most capable of supporting trails were loams, with a crumb or blocky structure and a moderate amount of organic matter.

69. Laing, C. C.
    1961. A report on the effect of visitors on the natural landscape in the vicinity of Lake Solitude, Grand Teton National Park, Wyoming. Unpubl. rep., 62 p. Natl. Park Serv., Grand Teton Natl. Park, Wyo.

Site-specific observations on trail, campsite, and grazing impacts provide some insights into general problems and offer some feasible solutions. The most severe trail problems resulted from horse use and use when trails were wet. The least amount of alteration occurred in dry meadows. Lack of ground cover and tree reproduction to replace the overstory were the major campsite problems. Grazing appeared to have surprisingly little effect, except for trampling when the soil was wet. The advantages of restricting the spatial distribution of use are discussed.

70. Landals, A. G., and L. J. Knapik.
    1972. Great Divide Trail: an ecological study of the proposed route, Jasper National Park and vicinity. Unpubl. rep., 251 p. Can. Wildl. Serv., Edmonton, Alta.

This study presents an excellent way to assess current and potential impact problems along a trail. Brief results of experimental trampling were incorporated, along with consideration of soil texture, drainage, slope steepness, and topography, into a table of fragility ratings. The ratings were then applied to 227 mi (363 km) of trails, with recommendations for trail maintenance techniques, where to establish campsites, and where the trail needs to be relocated. This discussion is followed by a section on general recommendations for trail planning, construction, and management. The authors emphasize the need for use concentration at designated campsites and the fact that rest-rotation of campsites is not feasible. The study is highly applicable to trail and campsite planning.

71. Landals, M., and G. W. Scotter.
    1973. Visitor impact on meadows near Lake O'Hara, Yoho National Park. Unpubl. rep., 184 p. Can. Wildl. Serv., Edmonton, Alta.

Comparisons of used and unused sites and experimental trampling were used to assess human impact on subalpine meadows in the Rocky Mountains of British Columbia. Much of the information, such as species resistance, is site specific in value, but useful generalizations include: fire scars were more rapidly recolonized when the rocks were left in place; community differences disappeared following trampling because *Carex nigricans* and *Sibbaldia procumbens* dominated essentially all disturbed sites; the impact of trampling frequency depended upon trampling intensity, with trampling spread out over time being less damaging at low trampling levels and concentrated trampling less damaging at high trampling levels (>100 walks in this study); enclosures suggested that reestablishment of a complete cover in the meadows would be rapid; and meadows were less fragile for camping than forest vegetation, but the authors felt that because of scenic attraction of the meadows, they should not be used for camping. This report is a good survey of the situation, although the adequacy of the controls used in both the experimental and comparison studies should be questioned, given the great compositional diversity and heterogeneity of subalpine meadows.

72. Landals, M., and G. W. Scotter.
    1974. An ecological assessment of the Summit Area, Mount Revelstoke National Park. Unpubl. rep., 197 p. Can. Wildl. Serv., Edmonton, Alta.

This report is a good, thorough assessment of recreational impacts on an area in the Rocky Mountains of British Columbia. Plant communities were described, mapped, and each assigned a fragility rating based on response to experimental trampling. Visitor use was described, as were current impacts. Surprisingly little damage was noted, aside from a proliferation of trails. Results of the experimental trampling showed that *Vaccinium membranaceum, Valeriana sitchensis,* and *Cassiope mertensiana* communities were highly susceptible to damage from trampling, with more than 50 percent of their cover being destroyed by 25 to 100 tramples; *Luetkea pectinata* and *Carex nigricans* communities were more resistant; and weekly trampling was usually more destructive than one-time trampling in the early summer (much of this difference may have resulted from recovery after early summer trampling). An index of vegetation fragility is provided, but it should be used cautiously; a follow-up study, by Campbell and Scotter (1975, reference *201*) showed a need to revise the rankings. Land managers are cautioned that, for the same piece of land, fragility ratings based on soils may contradict ratings based on vegetation and that intensive use will inevitably destroy all vegetation, regardless of fragility ratings. If this intensity of use is anticipated, soil fragility should be given more consideration than vegetation rankings.

73. LaPage, W. F.
    1962. Recreation and the forest site. J. For. 60:319-321.

Some ecological effects of camping in three New Hampshire State Parks were evaluated by comparing sample plots on campsites with neighboring unused controls. Soil compaction (penetration resistance) appeared to increase with intensity and duration of use, although it was not possible to adequately differentiate between the effects of site differences and of use differences. On the heavy-use sites, compaction was greatest 2 to 6 in (5 to 15 cm) below the surface. An apparent reduction in the diameter growth of *Pinus strobus* (white pine) growing in heavily used areas was also noted. This observation should be considered with caution, however, because this reduction could result from factors other than recreational use.

74. LaPage, W. F.
1967. Some observations on campground trampling and ground cover response. USDA For. Serv. Res. Pap. NE-68, 11 p. Northeast. For. Exp. Stn., Broomall, Pa.

This study followed the process of change in ground cover vegetation during the initial 3 years of a campground in the Allegheny National Forest, Pa. Existing vegetation was a treeless, abandoned field of grasses and forbs. During the first year of use, percent vegetative cover and the number of species decreased, with cover loss being greatest on the most heavily used sites. A threshold level was identified at about 200 camper-days, above which increased use resulted in much greater cover loss. By the end of the third year, cover was greater than at the end of the first, although the number of species continued to decline. By this time, there was no relationship between cover and either annual or cumulative use; some of the most lightly used sites had experienced the greatest amount of cover loss. The author concluded that an "initial and inevitable" cover loss occurs, which is related to amount of use, but that surviving cover in subsequent years is not related to amount of use (as long as some use occurs). Increases in cover after the first year resulted from the invasion or increased importance of trampling-resistant species. Grasses and "small plants" were more resistant than "tall plants," "dicots," and mosses. This is one of only a few studies of how campsite conditions change through time following their initial development.

75. Legg, M.
1973. Site factors useful in predicting deterioration of forest campsites in northern Michigan. Ph.D. diss. Mich. State Univ., East Lansing. 99 p.

Changes in soil and litter characteristics were monitored for 2 years on existing campsites (used for 2 years previously) and experimental trampling plots in northern Michigan. Generally, decreases in litter cover, depth, and weight, noncapillary pore space, and depth of the AO horizon were associated with increased campsite use and trampling intensity. Bulk density increased with trampling intensity, but was not related to amount of use on existing campsites; apparently maximum densities had already been reached on some sites. Sites with thick litter layers and AO horizons were less highly altered. Consequently, conifer sites were more durable, particularly at low-use levels, than hardwood sites. Campsite size increased over the period, but there was no consistent relationship between this increase and amount of use. Moreover, there was no relationship between campers' perception of campsite condition and either measured ecologic changes or amount of use. Recovery during 1 year on closed sites was insufficient to consider mere closure a viable means of site rehabilitation. Multiple regression equations were developed in order to assess the importance of site factors in predicting amount of change. Most of the material in this dissertation is site specific and dependent upon site and use history variables.

76. Legg, M. H., and G. Schneider.
1977. Soil deterioration on campsites: northern forest types. Soil Sci. Soc. Am. J. 41:437-441.

Percent organic litter cover, bulk density, macropore space, and depth to the A2 horizon were measured over two seasons on Michigan campsites which had been open for two seasons previously. Lightly used (100 to 150 visitor days/year), moderately used (200 to 250), and heavily used sites (300 to 500) in both hardwood and conifer stands were compared. Some of the results included: increased change in each parameter was associated with increased use; except in the case of depth to the A2 horizon, there are much greater differences between light-use sites and controls than between light- and heavy-use sites; depth to the A2 horizon will be reduced to zero within a few years on all campsites, regardless of use level; and except for depth to the A2 horizon, some winter recovery occurs, but this is usually offset by early July. The data presented in this publication suggest that most of the possible deterioration occurs within the first 5 years of use. (Compare with Merriam and others [1973, reference *98*].)

77. Lemons, J.
1979. Visitor use impact in a subalpine meadow, Yosemite National Park, California. *In* Proc. Conf. on Sci. Res. in the Natl. Parks. p. 1287-1292. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5. Gov. Print. Off., Washington, D.C.

Vegetative attributes and soil compaction were measured along a gradient of light to heavy use. *Muhlenbergia filiformis* and *Carex exserta* increased in prominence with increased use, while all other species decreased. The author stresses the nonsystematic nature of these changes and suggests that the response of individual plant species to human use has only qualitative predictive value. He suggests using a measure of community responses as a predictor of change. The coefficient of community, he suggests, is similar to the floristic dissimilarity value used by Cole (1978, reference *24*).

78. Leney, F. M.
1974. The ecological effects of public pressure on picnic sites. J. Sports Turf Res. Inst. 50:47-51.

A good, but brief, summary of a thesis which included observations of existing picnic sites in northeast Scotland and experimental trampling in the greenhouse and in the field. The most trampling-resistant plant communities had developed on what formerly were acid grassland and dry heather moor communities. The most resistant "natural" plant community was a grassland, which occurred on the lee side of dunes. Wet areas were usually denuded at lower trampling intensities than dry areas, and the ground cover of forests was much more susceptible than that of open areas. Experimental trampling in the greenhouse showed variable responses to trampling at the species level and even by different morphological types within one species. Moreover, these responses often differed markedly from responses in the field where the plant is competing with others, indicating that species response is highly variable, depending upon characteristics of the site and associated vegetation. On highly susceptible *Ammophila* dune grass sites, the effect of just 10 minutes of sitting was noticeable 2 years later. Recovery of picnic sites was much more rapid where some ground cover remained. On these sites, productivity approached normal levels within 1 year, although return to a normal species composition was slow and effects on the soil were considered largely irreversible.

79. Lesko, G. L., and E. B. Robson.
1975. Impact study and management recommendations for primitive campgrounds in the Sunshine-Egypt Lake Area, Banff National Park. North. For. Res. Cent. Inf. Rep. NOR-X-132, 86 p. Edmonton, Alta.

This report contains good, site-specific observations on campsite conditions in a heavily used backcountry area of subalpine forests and meadows in the Rocky Mountains of Alberta, Can. Each campsite was assigned a capability rating and an impact state, with criteria given for assigning quantitative values to each. Management recommendations are offered which take these ratings and use patterns into account. The authors suggest that subalpine meadows on alluvial fans or terraces with rocky soils can tolerate the most recreational use because they have thick Ah horizons, no restrictions to rooting depth, and are dominated by trampling-resistant grasses. Essentially no impact was detected away from the campsites and trails. This report is most useful for its methodology and the capability rating (discussed in greater detail in reference *170* by Lesko [1973]).

80. Liddle, M. J.

1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biol. Conserv. 7:17-36.

An excellent review of trampling research approaches and conclusions and how this information can be applied to management situations. Although it contains too much information to adequately review, some of the major conclusions include: trampling generally results in reduced vegetative cover and species richness (the number of species in an areal unit); trampling increases the bulk density and penetration resistance of soil; and trampling causes significant changes in the species composition of both plant and animal populations. The examples provide a good introduction to the study of the ecological effects of human trampling.

81. Liddle, M. J.

1975. A theoretical relationship between the primary productivity of vegetation and its ability to tolerate trampling. Biol. Conserv. 8: 251-255.

This paper reviews major generalizations about the effects of human trampling on vegetation and advances the hypothesis that trampling tolerance increases with the primary productivity of an ecosystem. Data are presented which show some support for this relationship, when tolerance is defined as the amount of pressure it takes to reduce cover to 50 pecent of its original amount. Alternative definitions of tolerance may be more applicable to some management situations, however.

82. Liddle, M. J., and P. Greig-Smith.

1975. A survey of tracks and paths in a sand dune ecosystem. I. Soils. II. Vegetation. J. Appl. Ecol. 12:893-930.

This study details vegetation and soil conditions associated with footpaths and vehicular tracks in a sand dune area of North Wales, utilizing experimental trampling and observations along existing paths. Bulk density and penetration resistance were higher on paths than in adjacent unused areas. Experimental trampling showed that as trampling intensified, further trampling caused less significant increases in soil compaction. Soil water content was abnormally high on tracks in dry areas and low on tracks in wet areas. The general effect of trampling on the vegetation was to produce more uniform stands, with reduced cover and number of species. Total biomass was greatest at path margins, in areas which received low levels of trampling. The paper also discusses the responses of individual species and growth forms to trampling. This was a well-conceived, detailed study which may be useful for methods and some broad generalizations, particularly in other coastal sand dune areas.

83. Liddle, M. J., and K. G. Moore.

1974. The microclimate of sand dune tracks: the relative contribution of vegetation removal and soil compression. J. Appl. Ecol. 11:1057-1068.

One of the indirect effects of trampling is to alter the microclimate as a result of soil compaction and vegetation removal. They report that on a dry sand dune track in North Wales, the diurnal soil temperature range increased 7° C, the result of a counteraction between the tendency of vegetation loss to increase temperature ranges and of soil compaction to decrease temperature ranges. This effect was less pronounced in moist areas and increases in air temperature ranges were less pronounced than increases in soil temperature ranges. Increases in windspeeds over the track were also noted.

84. Lime, D. W.

1972. Large groups in the Boundary Waters Canoe Area — their numbers, characteristics, and impact. USDA For. Serv. Res. Note NC-142, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

The author speculates that large groups cause more resource impacts than smaller groups because larger campsites are needed and because studies show that large groups tend to be more mobile and to stay longer. These suggestions are open to debate, however.

85. Lutz, H. J.

1945. Soil conditions of picnic grounds in public forest parks. J. For. 43:121-127.

The soils of picnic sites and adjacent controls in Connecticut State Parks were compared. On picnic sites, soil density was significantly greater, a result of a measured decrease in pore volume. Most of this decrease was a loss of noncapillary pore space, so that air capacity was significantly decreased, while field capacity remained constant on the sandy soil and increased on the sandy loam soil. These results suggest that aeration should be more of a problem than water deficiencies. Management suggestions include less removal of annual litter fall, rotation of sites, and artificial loosening of the soil.

86. McCool, S. F., L. C. Merriam, Jr., and C. T. Cushwa.

1969. The condition of wilderness campsites in the Boundary Waters Canoe Area. Minn. For. Res. Note 202, 4 p. Univ. Minn., St. Paul.

Increases in soil penetration resistance and decreases in duff depth were greater on island sites than mainland sites, while campsites on major canoe routes were larger, more highly compacted, and had greater reductions in duff depth than more remote sites. No consistent relationship to campsite location was found for vegetation cover, damage to trees, or trash. It was not possible to determine which of these differences were due to site differences and which were due to differences in use intensity.

87. McQuaid-Cook, J.

1978. Effects of hikers and horses on mountain trails. J. Environ. Manage. 6:209-212.

This paper provides an overview of recreational impacts on trails. Processes of trail degradation are discussed, as are some differences between horse and hiker impacts. The author

states, for example, that equestrian trails are usually less compacted and more deeply entrenched than pedestrian trails. No data are provided, however.

88. Magill, A. W.

1970. Five California campgrounds . . . conditions improve after five years' recreational use. USDA For. Serv. Res. Pap. PSW-62, 18 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

This paper describes changes in conditions over 5 years on five developed campgrounds in California. Over this period of time, no changes in tree density or growth rates were noticed. Undergrowth cover and litter cover and depth increased during the period. Unused sites, however, still had greater amounts of seedlings, saplings, shrubs, screening, and litter. Nevertheless, these observations suggest that the condition of established campsites does not continue to deteriorate through time. This conclusion must be tempered by the facts that barrier systems were erected at the beginning of the study period to keep vehicles off the sites and precipitation was above average or increasing over the period.

89. Magill, A. W., and E. C. Nord.

1963. An evaluation of campground conditions and needs for research. USDA For. Serv. Res. Note PSW-4, 8 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

One hundred thirty-seven developed Forest Service camping and picnic sites in California were surveyed. Tree seedlings were absent on 55 percent of the camps and even where present, their continued survival appeared to be doubtful. Twenty-eight percent of the overstory trees exhibited "poor vigor" and many of the vigorous trees had been mutilated by campers. Grasses and forbs were entirely absent on 95 percent of the individual units. On more than 70 percent of the sites, evidence was found of soil deterioration including hard-packed surfaces, small alluvial fans, rills and gullies, soil lines on tree bases, exposed roots, and exposed underground parts of camp facilities. Some *Abies procera* (noble fir) and *Abies concolor* (white fir) also had reduced diameter growth. Provides a general survey of conditions which suggest some apparent effects of use.

90. Malin, L., and A. Z. Parker.

1976. Ecological carrying capacity research: Yosemite National Park. Part III. Subalpine soils and wilderness use. 89 p. U.S. Dep. Commerce, Natl. Tech. Inf. Cent. PB-27-957.

Four types of subalpine soils were studied. It was concluded, apparently on the basis of observations and theoretical considerations, that wet meadow soils are most susceptible to damage and that better-developed soils on forested moraines can best tolerate use. Use of campsites on developed soils "seems to cause a structure alteration (compacted pan) which renders the soil more stable in the face of increased impact." Gravelly soils were not highly compacted due to their coarse texture. There is no data interpretation in the text, but a great amount of site-specific data have been included in the appendix.

91. Manning, R. E.

1979. Impacts of recreation on riparian soils and vegetation. Water Resour. Bull. 15:30-43.

Good overview of recreational impacts on soils and vegetation. The sections on spatial and temporal patterns are particularly useful. The author emphasizes that recreational impacts are highly concentrated but that impacted areas tend to expand with time. This suggests that impacted areas should be concentrated in areas of "high resource capability" and that managers should attempt to confine the spread of impacts. The author also notes that most impacts occur very rapidly and with very little use; therefore impacts are inevitable and, in many cases, cultural treatment of the vegetation will be necessary.

92. Marnell, L., D. Foster, and K. Chilman.

1978. River recreation research conducted at Ozark National Scenic Riverways 1970-1977: a summary of research projects and findings. U.S. Dep. Interior, Natl. Park Serv., Van Buren, Mo. 139 p.

This report contains chapters on such diverse topics as counting river users, social characteristics of users, and safety aspects of river recreation. The chapter on soil and vegetation impacts documents the same types of impacts frequently discussed elsewhere (soil compaction, change in species composition of the vegetation, and damage to trees).

93. Meinecke, E. P.

1928. The effect of excessive tourist travel on the California redwood parks. Calif. Dep. Natl. Resour., Div. Parks, Sacramento. 20 p.

This very early impact study reports some effects of recreational use on the root system of *Sequoia sempervirens* (redwood). In heavily impacted areas, the author noted decreases in the number of feeder roots and the frequency of branching, and changes in the vertical distribution of roots. This report is mostly of historical value.

94. Merkle, J.

1963. Ecological studies of the Amphitheater and Surprise Lakes cirque in the Teton Mountains, Wyoming. Unpubl. rep., 25 p. Natl. Park Serv., Grand Teton Natl. Park, Wyo.

This report is primarily concerned with describing the vegetation of this subalpine area. Some observations of recreational use and impact are included, however. The author emphasizes the highly localized nature of impacts and recommends regulation of packstock use such that this situation continues. Some data on species abundance in used and unused meadows are presented. There is, however, no indication of how similar these locations were environmentally.

95. Merkle, J.

1964. Ecological studies in Holly Lake cirque of the Teton Mountains, Wyoming. Unpubl. rep., 29 p. Natl. Park Serv., Grand Teton Natl. Park, Wyo.

Although the primary concern of this report is to describe the subalpine vegetation of the area, visitor use and resulting impacts are also briefly described. The author recommends containing impact by building hitch racks and "developed" campsites. This report is mostly site specific in value.

96. Merriam, L. C., Jr., and C. K. Smith.

1974. Visitor impact on newly developed campsites in the Boundary Waters Canoe Area. J. For. 72:627-630.

This article summarizes research reported in more detail in Merriam and others (1973, reference *98*).

97. Merriam, L. C., Jr., and C. K. Smith.

1975. Newly established campsites in the BWCA, restudy of selected sites—1974. Minn. For. Res. Note 254, 4 p. Univ. Minn., St. Paul.

This paper reports remeasurements taken on five campsites, 2 years after the study reported in Merriam and others (1973, reference *98*). No marked changes over the 2 years were noted, although some sites continued to deteriorate slowly while others improved. As the authors state, however, "The sample size was too small to make any real inferences." The possibility of using shrubs to prevent site expansion and wood chip mulch to reduce compaction is mentioned.

98. Merriam, L. C., Jr., C. K. Smith, D. E. Miller, and others.
1973. Newly developed campsites in the Boundary Waters Canoe Area — a study of five years' use. Univ. Minn. Agric. Exp. Stn., St. Paul, Bull. 511, 27 p.

Changes in soil penetration resistance, organic matter, vegetation cover, tree damage, and site size were monitored for 5 years and related to use intensity on 33 newly developed wilderness campsites. Results showed that the greatest increase in soil compaction occurred during the first 2 years, with little additional increase during the remaining 3 years of observation. The most striking change over time was not the increased **intensity** of any type of disturbance, but the increased **area** of disturbance. Several patterns of campsite expansion are discussed along with possible explanations for their development. Summary impact stages were calculated for each site and related to use levels. In general, impact increased with use in each vegetation type, but the relationship was highly curvilinear. Most impact occurred at low-use intensities, and in some vegetation types low use produced more impact than heavy use in other vegetation types. One should be cautious in interpreting these results, however, because the measured changes cannot be related to conditions existing prior to site construction. The fact that most impact occurs in the first 2 years the camp is used, while recovery takes much longer, suggests that campsite rotation would be self-defeating.

99. Monti, P., and E. E. Mackintosh.
1979. Effect of camping on surface soil properties in the boreal forest region of northwestern Ontario, Canada. Soil. Sci. Soc., Am. J. 43:1024-1029.

In comparison with undisturbed areas, campsites have lost their surface leaf litter horizons. Some of this organic matter is incorporated into the A1 horizons. Furthermore, the compacted surface mineral horizon on campsites is characterized by a reduction in both total porosity and noncapillary pore space. These changes are most pronounced more than 1 cm below the surface and are more evident on *Pinus banksiana* (jack pine) sites than on *Populus tremuloides* (aspen) sites.

100. Moorhead, B. B., and E. S. Schreiner.
1979. Management studies of human impact at backcountry campsites in Olympic National Park, Washington. *In* Proc. on Sci. Res. in the Natl. Parks. p. 1273-1278. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv. Trans. Proc. Ser. 5, Gov. Print. Off., Washington, D.C.

This paper describes a backcountry campsite impact inventory undertaken in Olympic National Park. It discusses results which also appear in Schreiner and Moorhead (1976, reference *115*). Again the authors stress the need to give individual site management a higher priority.

101. Nagy, J. A. S., and G. W. Scotter.
1974. A quantitative assessment of the effects of human and horse trampling on natural areas, Waterton Lakes National Park. Unpubl. rep., 145 p. Can. Wildl. Serv., Edmonton, Alta.

This report presents results of a one-season experimental trampling study in 10 plant communities in the Rocky Mountains of Alberta. Each community was subjected to one-time early summer, one-time midsummer, and weekly trampling for 5 weeks, at levels of 0, 25, 50, 100, 200, 300, 400, and 800 total tramples. Results indicated that lowland marsh and lowland and upland *Populus tremuloides* (aspen) communities were highly fragile; *Pinus contorta* (lodgepole pine), *Picea engelmannii* (Engelmann spruce), and *Abies lasiocarpa-Larix Lyallii* (alpine fir-alpine larch) were moderately fragile; subalpine lakeshore, *Dryas octopetala* (dryad), *Xerophyllum tenax* (beargrass), and prairie grassland communities were the most durable; in the prairie grassland, where horse and hiker impact were compared, horses destroyed three to eight times as much cover and created an order of magnitude more bare ground; in most cases, the greatest damage occurred with low levels of trampling; differences caused by the timing of trampling were generally less important than differences attributable to amount of trampling; and grasses and sedges were more resistant to trampling than dicotyledonous herbs and shrubs. This report provides a good data set, but one must keep in mind the short data collection period (recovery could not be considered) and the heterogeneity of the sample stands (trampled areas had to be compared to untrampled stands with somewhat different species composition). For a followup study with somewhat different results see Douglas and others (1975, reference *35*).

102. Palmer, R.
1972. Human foot impact: a preliminary report of the effects of human traffic on two alpine meadows in the Sierra Nevada. *In* Wilderness impact study report. p. 15-25. H. T. Harvey, R. J. Hartesveldt, and J. T. Stanley, eds. Sierra Club Outing Comm., San Francisco, Calif.

Preliminary results of experimental trampling suggest that meadow vegetation can be stepped on up to about five times before it is noticeably damaged. Two hundred tramples reduced total cover by only 6 percent, although stem breakage occurred after approximately 90 tramples. In *Phyllodoce breweri* heath, damage is obvious after 50 tramples, and after 210 tramples 90 to 95 percent of the plants had been destroyed. This suggests that the heather areas are more susceptible to trampling than grass-sedge meadows. No difference between the impact of lug soles and flat shoes was noticed. Few data are provided here, but a more detailed final report can be found in Stanley and others (1979, reference *124*).

103. Papamichos, N. T.
1966. Campground vegetative study, Rocky Mountain National Park, Colorado. Unpubl. rep., 101 p. Natl. Park Serv., Rocky Mt. Natl. Park, Colo.

This more detailed presentation of the results reported in Dotzenko and others (1967, reference *34*) includes a good review of the soil compaction problem. Depth of soil compaction exceeded 4 in (10 cm) on heavily used campsites. In comparison to essentially undisturbed parts of the campground, heavily used sites had higher bulk densities and lower organic matter and moisture content. There were cases, however, where organic matter and moisture content were higher on the used sites. In all cases, there was a much greater difference between essentially unused and moderately used parts of the campground than between moderate- and high-use areas. A negative correlation between organic matter and bulk density was reported as support for the statement that soils high in organic

matter were less readily compacted than soils low in organic matter. While this may be true, the correlation reported is primarily a result of similar responses by both variables to differences in trampling intensity; no correlation exists when the data are stratified by use intensity. The author's conclusion is that the best sites for development have medium-textured, well-drained, fertile soils, which are high in organic matter.

104. Peters, J. E.
1972. The ecological implications of trail use, Cypress Hills, Alberta. M.S. thesis. Univ. Alberta, Edmonton. 159 p.

Trails, in contrast to adjacent areas, had higher bulk density and pH, and lower organic matter, moisture content, and air-filled pore space values. The vegetation along trails also differed from that in undisturbed areas, with only two annuals, *Polygonum aviculare* and *Matricaria matricarioides*, surviving on the usually bare trail tread. At the trail edge, typical native species are largely replaced by weedy invaders, such as *Poa interior* and *Taraxacum officinale*. This thesis is most useful for its review of possible consequences of these changes and the pros and cons of various measurement techniques.

105. Rechlin, M. A.
1973. Recreational impact in the Adirondack high peaks wilderness. M.S. thesis. Univ. Mich., Ann Arbor. 65 p.

Backcountry campsites were studied and user perceptions were surveyed. The campsite investigations were not detailed, although it was possible to conclude that the areal extent of bare ground and disturbed forest increased with increasing use of the campsites. Most of this change occurred at the lower use levels. It was estimated that only 23.79 acres (9.63 ha) of the 219,570-acre (88 926-ha) area had been disturbed by camping. While this acreage is small, this is where people spend most of their time.

106. Rees, J., and J. Tivy.
1978. Recreational impact on Scottish lochshore wetlands. J. Biogeogr. 5:93-108.

A variety of interesting methods are integrated in an attempt to assess recreational impact and the relative vulnerability of lakeshore plant communities. It was concluded that walking causes more impact than running and that most species are damaged by trampling. The correlation between damage and trampling intensity was high, but not perfect. Vulnerability appeared to be more a function of shoot response (growth-form and leaf resistance) than root or rhizome response. Each species responded quite distinctively to trampling, however.

107. Ripley, T. H.
1962. Recreation impact on southern Appalachian campgrounds and picnic sites. USDA For. Serv. Res. Pap. SE-153, 20 p. Southeast, For. Exp. Stn., Asheville, N.C.

Multiple regression analysis related eight dependent variables to 18 independent variables on 280 developed camp and picnic sites in the southern Appalachians. The most important relationship for all sites studied was an association between increased high canopy closure and increases in bare ground, erosion, and root exposure. Thus, sites with dense tree canopies appeared to be more susceptible to damage. Although the relationship was less consistent, it also appeared that damage was particularly severe on infertile sites with thin, dry soils. The only variable that increased to any great extent with amount of use was percent bare ground. Other relationships were noted, but their meaning was often hard to interpret.

108. Ripley, T. H.
1962. Tree and shrub response to recreation use. USDA For. Serv. Res. Note SE-171, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.

This report briefly surveys the condition of trees and shrubs on developed camp and picnic sites in the southern Appalachian Mountains of Tennessee and North Carolina. Based on an index of disease infection, insect infestation, and decline, 27 species are ranked according to their ability to withstand recreational use. Conifers were more susceptible than hardwoods and the dense shade they cast induced greater site deterioration. Results should be applied carefully because the lack of controls makes it impossible to be certain that observed tree condition is a result of recreational use.

109. Rogova, T. V.
1976. Influence of trampling on vegetation of forest meadow and whortleberry-moss-pine forest cenoses. Sov. J. Ecol. 7:356-359.

The effects of experimental trampling on meadow and forest vegetation in the USSR are discussed. Damage was greater after 350 passes/week than after 15 passes/week, although this difference was much less significant in the meadow. Despite greater resistance to deterioration at low trampling levels, forest understory vegetation recovered much more slowly than meadow vegetation, regardless of trampling intensity. The study period lasted only 1 month, however, so that results should be applied with caution. Trampling frequency, at rates of either 50 passes per day or 175 passes on 2 days of every 7 (same total number of passes), had little effect on rate of deterioration, but recovery was faster where trampling was equally distributed in time. Morphological characteristics of resistant and susceptible plants are also discussed.

110. Root, J. D., and L. J. Knapik.
1972. Trail conditions along a portion of the Great Divide trail route, Alberta and British Columbia Rocky Mountains. Res. Counc. Alberta Rep. 72-5, 24 p. Edmonton, Alta.

This report includes a good discussion of major types of trail damage, how damage occurs, and how it can be avoided on a trail in the Canadian Rockies. Degree of damage was a function of trail slope and orientation, soil type, and ground water conditions. Erosion increased on steep trails, particularly where they went directly uphill. The greatest amount of erosion, however, was found on alluvial plains with only 2 to 5 degree slopes, an illustration of the importance of soil texture. Alluvial plains have a high silt composition, which is easily eroded by running water. Other problems occurred where trails were located below areas of ground water discharge, snowbanks, or in areas with wet soils. Recommendations on how to locate and design a trail to avoid these problems are included.

111. Rutherford, G. K., and D. C. Scott.
1979. The impact of recreational land use on soil chemistry in a provincial park. Park News 15:22-25.

Used and unused areas, both in forest and grassland, were compared in a study of developed campsites in Brown's Bay Provincial Park, Ont., Canada. Soils in campsites had less organic matter than controls, with this difference much more pronounced in forested areas. Campsite soils were less acidic, had higher chloride concentrations, and lower nitrate concentrations. Phosphate increased on campsites in grassland and

decreased on forested sites. Cation exchange capacity and magnesium, potassium, and sulfate concentrations did not change in any consistent manner. The authors conclude that these chemical changes result from changes in organic matter content which are more pronounced in forested areas.

112. Satchell, J. R., and P. R. Marren.
    1976. The effects of recreation on the ecology of natural landscapes. Nat. Environ. Ser. 11, Counc. Eur., Strasbourg, France, 117 p.

This report summarizes European research on ecological impacts resulting from recreation. It describes methods of measurement and analysis and reviews what is known about impacts on the soils, vegetation, and fauna of the following ecosystems: coastal ecosystems, grasslands, montane ecosystems, heaths, woodlands, footpaths and roads, maquis and other Mediterranean vegetation types, and freshwater ecosystems. A discussion of alternative means of managing impacts and an extensive bibliography are also included. The conclusion that research in recreational ecology has been scanty and uncoordinated is supported by obvious information gaps in the review and the fact that research results are usually not comparable.

113. Schreiner, E. G.
    1974. Vegetation dynamics and human trampling in three subalpine communities of Olympic National Park, Washington. M.S. thesis. Univ. Wash., Seattle. 150 p.

Three subalpine meadows were trampled at a rate of 100 walks/week for 1 week and 5 weeks. These two treatments were compared with a control site during the 5-week study period. As hypothesized, hemicrytophytes were generally more resistant than other life forms, although each life form was variable in its response to trampling. Lichens were particularly sensitive. The author suggests, however, that trampling resistance may be more a matter of leaf morphology than of bud location. (See Rees and Tivy [1978, reference *106*].) The response of individual species to trampling was also variable, apparently a result of differences in site factors and plant form. In all three meadow types, vegetation damage was much greater following 500 walks than following 100 walks. Data on change in cover and frequency by species are provided.

114. Schreiner, E. G.
    1975. Investigative methods for the study of site response to human trampling. Unpubl. pap. presented at the Resour. Manage. Conf., U.S. Dep. Interior, Natl. Park. Serv., Pac. Northwest Reg., Seattle, Wash. 15 p.

This paper discusses the advantages and disadvantages of various research techniques. (Compare with Burden and Randerson [1972, reference *21*].) It also describes some measureable parameters for quantitative investigations and includes a bibliography. The author concludes that more emphasis should be given to long-term studies.

115. Schreiner, E. G., and B. B. Moorhead.
    1976. Human impact studies in Olympic National Park. *In* Proc. Symp. on Terrestrial and Aquatic Ecol. Stud. of the Northwest. p. 59-66. East. Wash. State Coll., Cheney.

A measure of bare ground at campsites was related to percent coarse fraction in the surface soil, winter snow depth (using lichen height as an indicator), and canopy cover. Due to great variability both between and within groups of campsites, few significant patterns were found for the park as a whole. The strongest relationship showed that bare ground increased as canopy cover increased, when sites in close proximity to each other were compared. The authors conclude that the degree of heteorogeneity they found suggests that each area within the park must be managed individually.

116. Settergren, C. D.
    1977. Impacts of river recreation use on streambank soils and vegetation — state-of-the-knowledge. *In* Proc. River Recreation Manage. and Res. Symp. p. 55-59. David W. Lime and Clyde A. Fasick, eds. USDA For. Serv. Gen. Tech Rep. NC-28. North Cent. For. Exp. Stn., St. Paul, Minn.

This is a brief summary of research approaches to the study of recreational impacts and some generalizations from the literature. It provides a good overview of recreational impacts on many types of areas, not just along rivers.

117. Settergren, C. D., and D. M. Cole.
    1970. Recreation effects on soil and vegetation in the Missouri Ozarks. J. For. 68:231-233.

Paired plots, in used and unused areas, were examined to determine the effects of recreational use on the soils of three 18-year-old camping areas. On used areas, soils had more rock close to the surface (presumably reflecting a loss of finer particles by erosion), fewer roots in the upper 6 in (15 cm) of soil (where they are concentrated in unused areas), a lack of organic matter in the surface horizon, and increased bulk density. Although not enough data on moisture availability is presented to evaluate the results, the authors conclude that moisture, particularly at the surface, is a limiting factor on used sites. Consequences of these effects are noted and it is suggested that soils which are naturally droughty, such as those studied, should not be developed for recreational use.

118. Sharsmith, C. W.
    1959. A report on the status, changes and ecology of backcountry meadows in Sequoia and Kings Canyon National Parks. Unpubl. rep., 122 p. U.S. Dep. Interior, Natl. Park Serv., Sequoia and Kings Canyon Natl. Parks, Three Rivers, Calif.

Backcountry meadows which received little grazing use at the time of the study were slowly improving, while heavily used areas were being invaded by lodgepole pine and false hellebore (*Veratrum*) and were eroding. Some of these invasions had advanced as much as 100 ft (30 m) in the last 10 to 12 years. At the time of the report, no meadows had suffered irreversible damage, but several were in need of immediate help. The method used was primarily a comparison of 1958 conditions with photographs taken in 1940. More recent analyses of the same meadows can be found in Sumner (1968, reference *181*) and Stanley and others (1979, reference *124*).

119. Singer, S. W.
    1971. Vegetation response to single and repeated walking stresses in an alpine ecosystem. M.S. thesis. Rutgers Univ., New Brunswick, N.J. 69 p.

This experimental study compared the effects on vegetation of different trampling intensities and frequencies (weekly versus one-time trampling). An alpine meadow in Mt. Rainier National Park was trampled weekly, at various intensities up to 150 tramples/week, for 8 weeks. In a second experiment the same meadow was trampled once at various intensities up to 150 tramples. By the end of 8 weeks, vegetation subjected to 75 to 150 tramples/week was significantly more degraded than

vegetation trampled 9 to 45 times/week. There was, however, no statistical difference in percent cover loss between areas trampled 9 and 45 times/week, and, in terms of cover loss, the plots which received the lowest trampling intensity were more similar to the plots receiving the most trampling than to the control plots. The same number of walks dispersed over time produced more damage than when that number of walks was concentrated in time. As with many of the other conclusions, however, this is based on just one example and should be treated as an hypothesis. This thesis is a good example of the type of data that needs to be collected at more sites and over longer periods of time if vegetation response is to be related to use characteristics.

120. Slatter, R. J.
1978. Ecological effects of trampling on sand dune vegetation. J. Biol. Educ. 12:89-96.

Transects oriented perpendicular to paths were utilized to document decreases in plant height, changes in species composition, and increases in bulk density along the paths. Monocotyledons and species with a hemicryptophytic or therophytic growth form survived heavy trampling more frequently than other species. Substantiates most of the findings of other authors (see Liddle [1975, reference *80*]).

121. Speight, M. C. D.
1973. Outdoor recreation and its ecological effects: a bibliography and review. Discuss. Pap. in Conserv. 4, Univ. College, London. 35 p.

This paper is a valuable compilation of the literature and an intelligent, succinct review of the state-of-the-art. It includes an overview of the effects of recreation on soils, vegetation, and wildlife, and how this information can be applied to the management situation. A good introduction to the literature, particularly the author's evaluation of shortcomings and progress in the field.

122. Spiridinov, V. N.
1979. Change in species composition of the herbage in herb birch forest under the effect of recreational stress. Sov. J. Ecol. 9:377-379.

With increasing recreational stress, expressed as the area of compacted soil surface, species richness decreases and weedy invaders become more prominent in the understory. Many of these invaders (such as, *Poa pratensis, Phleum pratense, Polygonum aviculare*, and *Platago* spp.) are commonly found on recreational sites in North America as well.

123. Stankey, G. H., and D. W. Lime.
1973. Recreational carrying capacity: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-3, 45 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This bibliography contains 208 references on the following dimensions of carrying capacity: documentation of the need for more recreation space, definition of recreational carrying capacity, biological investigations of carrying capacity, investigations of esthetic carrying capacity, and managing for carrying capacity.

124. Stanley, J. T., Jr., H. T. Harvey, and R. J. Hartesveldt.
1979. A report on the wilderness impact study: the effects of human recreational activities on wilderness ecosystems with special emphasis on Sierra Club wilderness outings in the Sierra Nevada. Outing Comm., Sierra Club. San Francisco, Calif. 290 p.

This report includes research results reported in Palmer (1972, reference *102*), Palmer (1975, reference *255*), and Strand (1972, reference *126*). Another paper by Strand on recovery of meadows following trampling by packstock showed that more recovery took place after 1 year in dry meadows than in very wet meadows. A paper by Palmer on revegetating multiple trails suggested the value of the following method: dig up and set aside the sod ridges between trails; break up the compacted soil and add sand to the trail tread until it reaches the level of the adjacent surface; then replant sod in the loosened soil. The report also contains papers on user characteristics, firewood production and use, waste disposal, and management recommendations. This is a useful collection of research results and opinions on wilderness management. The authors note numerous limitations to the studies, however, and many of the opinions are debatable.

125. Stelmock, J. J., and F. C. Dean.
1979. Vegetation trampling effects analysis — 1975 plots, Mount McKinley National Park, Alaska. Unpubl. rep., 67 p. U.S. Dep. Interior, Natl. Park Serv., Mt. McKinley Natl. Park, Alaska.

Stem counts of vegetation in plots at varying distances from trails were utilized to measure trampling effects. Results were highly variable and difficult to interpret due to small quadrat size. Generally, vegetation cover and height, species richness, and the density of most species decreased within 1 m of the trail. The authors conclude that the sensitivity of plants to trampling is highly variable and dependent upon site-specific characteristics of the community. A brief photographic study of trail recovery is also included. The report is most valuable for its evaluation of possible sampling and analysis techniques.

126. Strand, S.
1972. Pack animal impact: progress report on pack animal impact on wilderness meadows. *In* Wilderness impact study report. p. 37-48. H. T. Harvey, R. J. Hartsveldt and J. T. Stanley, eds. Outing Comm., Sierra Club, San Francisco, Calif.

Preliminary results of a study of packstock impact in the Sierra Nevada. Most meadows are recovering from earlier heavy use by domestic livestock and packstock, but the rate and type of recovery is dependent upon the amount of continuing use. The most important site factor influencing amount of impact appears to be fragility of the substrate, primarily the moisture content of the soil. The difference in impact after 100 tramples by hikers and by horses was negligible in dry areas, but packstock caused much more damage in wet areas. The final report appears in Stanley and others (1979, reference *124*).

127. Strand, S.
1972. An investigation of the relationship of packstock to some aspects of meadow ecology for seven meadows in Kings Canyon National Park. M.A. thesis. Calif. State Univ., San Jose. 125 p.

This thesis is basically an expanded account of the results reported in reference 126. There is, however, a more complete discussion of general ecological consequences of packstock use which is of additional interest.

128. Streeter, D. T.
1971. The effects of public pressure on the vegetation of chalk downland at Box Hill, Surrey. *In* The scientific management of animal and plant communities for

conservation. p. 459-468. E. Duffey and A. S. Watt, eds. Blackwell Sci. Publ., Oxford, Eng.

Trampling resulted in changes in the species composition and nutrient status of the soil. Moderate trampling resulted in nutrient enrichment while heavy trampling led to nutrient impoverishment. Vigorous, trampling-resistant species, which often require fertile soils, can invade trampled areas which receive moderate amounts of trampling. To some extent, then, "use actually produces a sward that is better adapted to the visitor pressure to which it is subjected." Thus both trampling stress and subsequent changes in fertility contribute to shifts in species composition.

129. Sumner, L., and R. M. Leonard.
1947. Protecting mountain meadows. Sierra Club Bull. 32(5):53-69.

This paper briefly discusses how use by packstock is destroying mountain meadows in the Sierra Nevada. The most interesting part is a sequence of photographs illustrating meadows at various stages of deterioration.

130. Sutton, S. W.
1976. The impact of floaters on the Ozark National Scenic Riverways. M.S. thesis. Univ. Missouri, Columbia. 152 p.

Areas frequently visited by recreational floaters were studied. Places which received heavy use, during the 1-year observation period, had less ground cover, fewer plant species, less litter cover, more rock and bare soil, and higher bulk density than unused areas. Impacts were more pronounced on stable soils than on temporary gravel bar sites.

131. Tachibana, H.
1969. Vegetation changes of a moor in Mt. Hakkoda caused by human treading. Ecol. Rev. 17(3):177-188.

The author relates vegetational differences in a sphagnum moor on Mt. Hakkoda, Japan, to differences in trampling pressure. Differences in height of vegetation, species composition, and denudation of the peat layer were related to an inferred human impact gradient. Primarily of interest as a case study from Japan.

132. Thornburgh, D. A.
1962. An ecological study of the effect of man's recreational use at two subalpine sites in western Washington. M.S. thesis. Univ. California, Berkeley. 50 p.

An early attempt to document the effect of recreational use on soil and vegetation at two subalpine sites in the Cascade Mountains of Washington, one at Klapatche Park in Mt. Rainer National Park and one at Image Lake in the Glacier Peak Wilderness Area. Used areas, identified visually and with the aid of a soil penetrometer were compared with undisturbed areas which often had to be found in adjacent drainages. Therefore, results must be interpreted cautiously. Heath species, such as *Phyllodoce empetriformis,* one of the dominants in the area, were quite susceptible to trampling damage, while *Antennaria lanata* was relatively resistant. The transition from disturbed to undisturbed vegetation was most abrupt in the forested areas. Mostly site specific in value.

133. Thornburgh, D. A.
1970. Survey of recreational impact and management recommendations for the subalpine vegetation communities at Cascade Pass, North Cascades National Park. Unpubl. rep., 42 p. U.S. Dep. Natl. Park Serv., North Cascades Natl. Park, Wash.

This report provides an evaluation of the susceptibility of species and plant communities to disturbances associated with camping. *Carex nigricans* subalpine meadows were the most resistant to use while severe disturbance was characteristic of campsites in *Tsuga mertensiana-Abies amabilis* (mountain hemlock-silver fir) forests. No recovery was observed following the use of bark chips or burlap nets on disturbed sites. The author suggests cultivating the soil and sowing native seeds, as well as careful control of camping. (See Miller and Miller [1976, reference *247*].) This report is largely site specific in value.

134. Thornburgh, D. A.
1973. Survey of recreational impact and management recommendations for the subalpine vegetation at Easy Pass, North Cascades National Park. Unpubl. rep., 19 p. Natl. Park Serv., North Cascades Natl. Park, Wash.

This site-specific description of damage to subalpine vegetation offers some suggestions for minimizing potential damage to a relatively pristine area.

135. Trew, M. J.
1973. The effects and management of trampling on coastal sand dunes. J. Environ. Plan. Pollut. Control 1(4):38-49.

This paper provides some data relating soil and vegetation changes to amount of trampling on two dune areas in southern England. It is primarily a general discussion of factors to be considered in managing dune areas for recreation.

136. Trottier, G. C., and G. W. Scotter.
1973. A survey of backcountry use and the resulting impact near Lake Louise, Banff National Park. Unpubl. rep., 254 p. Can. Wildl. Serv., Edmonton, Alta.

Mostly of site-specific value, this report describes visitor use and resulting impacts in a predominantly day-use area. Visitor use was determined from trail registers and user preferences were assessed with a questionnaire. Trail problems are described and the impact of camping on meadows is discussed. A good example of an impact study that contains methods which might be usefully applied in other areas.

137. Trottier, G. C., and G. W. Scotter.
1975. Backcountry management studies, the Egypt Block, Banff National Park. Unpubl. rep., 178 p. Can. Wildl. Serv., Edmonton, Alta.

Visitor attitudes and recreational impacts were assessed in an area in the southern Canadian Rockies of Alberta. Although mostly site specific in value, the report provides a good discussion of trail problems and offers useful management suggestions. General conclusions include: (1) poor trail conditions usually resulted from inadequate trail design, location, and maintenance, rather than overuse; (2) the major exceptions to this were trails used by large horse parties; (3) trail deterioration problems were more esthetic than ecologic; and (4) impact problems were highly localized.

138. Van der Werf, S.
1970. Recreatie-invloeden in Meijendel. [Recreation influences in Meijendel — a dune valley north of the Hague.] Meded. LandbHoogesch. Wageningen 70-17:1-24. [In Dutch, English summary.]

Recreation impacts were assessed in an area of sand dunes. The vulnerability of different types of terrain and vegetation was assessed and mapped, along with the current amount

of disturbance. A good example of how to base management on a thorough assessment of the current situation and potential for damage.

139. Wall, G.

1977. Impacts of outdoor recreation on the environment. Counc. Plan. Libr. Exch. Bibliogr. 1363, 19 p. Monticello, Ill.

A bibliography (not annotated), containing 183 references on the ecological impacts of various dispersed recreational activities, such as snowmobiling and hiking. Theses and published literature, both from Europe and North America, are the primary sources. All references have been written in the English language.

140. Wall, G., and C. Wright.

1977. The environmental impact of outdoor recreation. Dep. Geogr. Publ. Ser. 11, 69 p. Univ. Waterloo, Ont.

A good, general introduction to the subject, which briefly summarizes classic research in the field. It includes discussions of impacts on geology, soil, vegetation, water quality, wildlife, and air. Important research gaps are also identified. The treatment of the subject is not as insightful or interpretive as the review by Speight (1973, reference *121*), but it provides a good, basic overview of recreational effects on the environment.

141. Ward, R. M., and R. C. Berg.

1973. Soil compaction and recreational use. Prof. Geogr. 25:369-372.

Brief discussion of a study of soil compaction in Waterloo Recreation Area, Mich. Soil compaction was measured with a pocket penetrometer along transects across trails and campgrounds. Mean penetration resistance in frequently trampled areas was approximately 16 times greater than that in adjacent unused areas. The highly localized nature of recreational impacts is emphasized.

142. Weaver, T., and D. Dale.

1978. Trampling effects of hikers, motorcycles and horses in meadows and forests. J. Appl. Ecol. 15:451-457.

Experimental trampling was applied by hikers, horses, and motorcycles to a *Festuca idahoensis-Poa pratensis* grassland and a *Pinus albicaulis* (whitebark pine)-*Vaccinium scoparium* forest in the Rocky Mountains of Montana. Bare ground, trail width, trail depth, and bulk density increased with increasing number of tramples, up to the maximum of 1,000 passes. This relationship was distinctly curvilinear, however, with the greatest change in these variables occurring at low levels of trampling. Trails deteriorated more rapidly on sloping sites (15°) than on level ground. Creation of bare ground occurred more rapidly on the forested site, while trail depth and compaction were greater on the stone-free meadow soils. This suggests greater vegetation damage in forest and greater erosion problems in meadows. Both hikers and horses caused more damage walking downhill than uphill and hikers caused significantly less damage than either horses or motorcycles. This paper is a good attempt to relate use characteristics to the immediate effects of this use.

143. Westhoff, V.

1967. The ecological impact of pedestrian, equestrian and vehicular traffic on vegetation. *In* Proc. Int. Union for the Conserv. of Nat. and Nat. Resou., New Ser. 7. p. 218-223.

This paper presents a general overview, briefly discussing both beneficial and harmful influences of traffic on vegetation. Many ecologically specialized and interesting species respond favorably to the steep environmental gradient which occurs perpendicular to a travel route. On the other hand, excessive traffic results in impoverishment of the vegetation and compaction of the soil.

144. Whitson, P. D.

1974. The impact of human use upon the Chisos Basin and adjacent lands. Natl. Park Serv. Sci. Monogr. Ser. 4, 92 p. Gov. Print. Off., Washington, D.C.

This survey of human impacts on the vegetation of a part of Big Bend National Park, Tex., provides detailed, mostly site-specific observations of changes associated with trails and campgrounds. It provides a good discussion of how horse impact differs from hiker impact. Management suggestions include a program for revegetation, eradication of introduced species, and tighter controls on concessions and recreational activities. The survey is valuable as one of few discussions of human impact in this geographic area.

145. Whittaker, P. L.

1978. Comparison of surface impact by hiking and horseback riding in the Great Smoky Mountains National Park. Manage. Rep. 24, 32 p. U.S. Dep. Interior, Natl. Park. Serv., Southeast. Reg.

This study employed experimental trampling at various use intensities to compare the impact of horses, hikers with lug soles, and hikers with soft soles. Study sites included a pasture, an unmaintained footpath, and maintained trails in a mesic and xeric environment. Despite the short study period (2-½ weeks) some interesting results included: type of shoe made relatively little difference, except heavy shoes caused more redistribution of leaf litter; trampling on trails **reduced** compaction, regardless of type of use, but horse traffic in pastures reduced compaction and foot traffic increased compaction; reduced compaction resulted from churning the soil into dust or mud, a process that increased the potential for severe erosion and that was much more pronounced with horse use; height of vegetation and depth of leaf litter were reduced by trampling, with most of the reduction occurring at the lowest trampling intensities and with horse use causing greater reductions; site differences explained more of the variability in amount of change than trampling intensity, except where heavy horse use caused severe damage; trails through mesic forests were more severely altered, particularly by horse use than trails through xeric forests; and horse use not only caused greater damage but the types of changes, such as increased erosion potential, were more damaging.

146. Willard, B. E., and J. W. Marr.

1970. Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colorado. Biol. Conserv. 2:257-265.

Observations of human impact near parking lots attest to the considerable effect of concentrated trampling on tundra vegetation. Although low levels of trampling (less than five people every few days) caused no noticable damage, the authors concluded that trampling by hundreds of people could destroy tundra ecosystems in a matter of weeks. In one area, which had been used for 38 years, all of the vegetation was gone and the A horizon was eliminated over 95 percent of the area. Observations on the susceptability to trampling of various species, growth forms, and plant communities are included. Generally, moist sites were more highly damaged than dry sites. Graminoids were more resistant than cushion plants,

which were more resistant than lush herbs. A scale of visitor impacts is also included.

147. Willard, D. E.

1971. How many is too many? Detecting the evidence of over-use in State parks. Landscape Archit. 61(2):118-123.

This article touches very briefly on many subjects related to overcrowding and the ecological impacts of recreation. Much attention is focused on the lack of tree regeneration in the Texas campgrounds under discussion.

148. Young, R. A.

1978. Camping intensity effects on vegetative ground cover in Illinois campgrounds. J. Soil Water Conserv. 33:36-39.

Vegetative characteristics of campsites receiving light, moderate, and heavy use were compared to control plots. Light use resulted in significant increases in bare ground and percent monocotyledonous species in the ground cover, and decreases in the number of species present, amount of organic litter and shrub cover. Where use exceeded 33 days/year (moderate use) there were further increases in bare ground and decreases in the number of species, but no further changes in any of the other variables. No additional changes occurred as use increased beyond 50 days/season. No differences in overstory vegetation were noted between controls and campsites. The suggestion is that most of the vegetative changes on campsites occur at low-use levels and differences in condition resulting from use intensity differences become insignificant at high-use intensities.

149. Young, R. A., and A. R. Gilmore.

1976. Effects of various camping intensities on soil properties in Illinois campgrounds. Soil Sci. Soc. Am. J. 40:908-911.

Chemical and physical soil changes are described on the same campsites studied and reported on in Young (1978, reference *148*). Soil compaction (resistance to penetration) and pH increased with use, as did organic matter, a result which contrasts with findings from most other areas. Quantities of exchangeable calcium, potassium, phosphorus, sodium, and nitrogen also increased with use. Most of these changes occurred with only light use; beyond a use level of 34 days/season there were additional increases only in pH, calcium, and compaction. This is one of the few studies of chemical changes in the soil resulting from recreational use. The increases in organic matter and nutrient content with use intensity suggest that a compacted layer may "protect" the underlying soil from leaching.

IMPACT MANAGEMENT

(Also see reference numbers *5, 11, 14, 24, 32, 44, 53, 56, 58, 70, 71, 72, 79, 91, 100, 112, 115, 121, 123, 124, 133, 134, 135, 136, 137, 138, 144, 194, 195, 208, 226, 260, and 277.*)

150. Bainbridge, D. A.

1974. Trail management. Bull. Ecol. Soc. Am. 55(3):8-10.

This plea for more research related to trail management identifies research gaps that need to be filled. This is a good, brief introduction to what still needs to be learned about trail problems.

151. Bayfield, N. G.

1971. A simple method for detecting variations in walker pressure laterally across paths. J. Appl. Ecol. 8:533-535.

This paper describes the use of transects of fine wires projecting from the ground (trampleometer pins) for determining the lateral distribution of trampling across paths. This technique measures relative trampling pressure rather than absolute numbers of people. Two examples illustrate the much broader lateral extent of trampling along paths through open as opposed to wooded areas.

152. Bohart, C. V.

1968. Good recreation area design helps prevent site deterioration. J. Soil Water Conserv. 23:21-22.

This brief general discussion of the importance of facility design to recreation management includes a few examples that may be applicable to backcountry.

153. Butler, E. A., and D. M. Knudson.

1977. Recreational carrying capacity. Element 16 of the 1975-79 Ind. Outdoor Recreat. Plann. Program, Div. Outdoor Recreat., Ind. Dep. Nat. Resour., Indianapolis. 124 p.

A literature review and report of preliminary study results related to recreational carrying capacity in developed recreation areas in Indiana. The authors briefly discuss the concept of carrying capacity and review some of the more important studies. Results of a visitor survey and a very brief campsite impact study are included. The report contains some interesting data, but most of the value is in the literature review.

154. Cieslinski, T. J., and J. A. Wagar.

1970. Predicting the durability of forest recreation sites in northern Utah — preliminary results. USDA For. Serv. Res. Note INT-117, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

A configurated roller was used to simulate trampling on sites in a lodgepole pine and aspen forest. Amount of surviving vegetation after 132 passes administered over an 11-week period was used as the dependent variable in a multiple regression analysis. The most durable sites were on steep northeast slopes, at low elevations. These results, however, were based on the amount of vegetation left on the site, not the amount that was destroyed by trampling. Further, these results do not consider recovery and are highly site specific. The authors recognized this and their primary conclusions are concerned with the apparent value of the method.

155. Coleman, R. A.

1977. Simple techniques for monitoring footpath erosion in mountain areas of north-west England. Environ. Conserv. 4:145-148.

Monitoring erosion can help managers contain the deterioration of footpaths. Depending upon the time-span involved and the required accuracy, several monitoring methods are possible. Long-term trends can be measured on aerial photographs. Short-term trends can be identified by taking vertical measurements from either a taut cord or wire, or from a rigid bar attached to fixed points on both sides of the footpath. Practical suggestions, sample results, and advantages and disadvantages of each method are provided.

156. Cordell, H. K.

1975. The literature of planning and managing intensively developed natural resource recreation sites. *In*

Southern States Recreation Res. Workshop. p. 273-302. USDA For. Serv. Southeast. For. Exp. Stn., Asheville, N.C.

A step-by-step process is outlined for planning and managing developed recreation sites. The information here might be used for backcountry areas if the appropriate constraints of site access and design are considered. A bibliography of 130 references is included with codes that show to which step in the process they apply.

157. Craig, W. S.
1977. Reducing impacts from river recreation users. *In* Proc. River Recreation Manage. Res. Symp. p. 155-162. USDA For. Serv. Gen. Tech. Rep. NC-28. North Cent. For. Exp. Stn., St. Paul, Minn.

This report briefly discusses methods of preventing impacts and rehabilitating campsites in dispersed use settings. The author advocates confining visitors to designated campsites unless use levels are very low. A discussion of possible site restoration practices is also included.

158. Dalle-Molle, J.
1977. Mt. Rainier's backcountry system — a highly restrictive example. *In* Proc. Idaho Trail Symp. p. 32-41. Univ. Idaho, Moscow.

This paper discusses Mt. Rainier's backcountry management policies, reasons for these policies, and what will be done in the future to improve upon them. The author cites as major policy areas, rationing and use dispersal, minimum impact education, behavior regulation, and site restoration. An interesting discussion of methods for reducing impact in a heavily used National Park.

159. Densmore, J., and N. P. Dahlstrand.
1965. Erosion control on recreation land. J. Soil Water Conserv. 20:261-262.

The authors, both soil scientists, provide a brief general discussion of how recreation managers should plan facilities in such a manner that erosion potential is minimized. They stress the need for adequate water disposal and maintenance of vegetative cover.

160. Epp, P. F.
1977. Guidelines for assessing soil limitations for trails in the Southern Canadian Rockies. M.S. thesis. Univ. Alberta, Edmonton. 164 p.

A good study of how differences in various soil parameters affect trail condition. Trail condition was assessed at sites where all soil parameters but one could be held constant. Trail condition was judged on the basis of trail width, depth, muddiness, dustiness, loose and embedded coarse fragments, and roots. The major problem with this study design is that interaction between variables was not evaluated except in an anecdotal manner, that is, the conclusions for each soil parameter only apply strictly to the single set of environmental conditions which were held constant. Nevertheless, a useful table of limitations is developed which includes texture, gravel content, cobble content, stoniness, rockiness, slope, wetness, and flooding. Such a table could be very useful in locating trails, as long as interactions between parameters are taken into account. This document is useful, as is, in areas in the Northern Rocky Mountains and the method developed could be successfully applied elsewhere.

161. Fay, S. C., S. K. Rice, and S. P. Berg.
1977. Guidelines for design and location of overnight backcountry facilities. Unpubl. rep., 23 p. USDA For. Serv. Northeast. For. and Exp. Stn., Broomall, Pa.

This report is a good, practical discussion of some factors to consider when locating and designing backcountry campsites. Locational factors include soil, topography, aspect, vegetation, and water supply. Design considerations include layout, access, privy facilities, vegetation, fireplaces, and permanent photo points. A simplified table summarizes the suitability of various soil and vegetation types for facility location, but, as the authors note, the interaction of these factors makes such a summary somewhat misleading. Nevertheless, it provides good ideas which the manager should consider.

162. Frissell, S. S.
1978. Judging recreation impacts on wilderness campsites. J. For. 76: 481-483.

A synopsis of campsite condition classes and management prescriptions, which are described in more detail in Frissell (1973, reference *44*).

163. Hamburg, S.
1976. Backcountry trails. *In* Backcountry management in the White Mountains of New Hampshire. p. 52-55. William R. Burch, Jr. and Roger W. Clark, eds. Sch. For. Environ. Stud. Work. Pap. 2, Yale Univ., New Haven, Conn.

The author presents his opinions about how to locate and maintain a trail system. He suggests moving most trails from ridges to valleys and gently sloping hills, in contrast to the recommendations of some other researchers, such as Landals and Knapik (1972, reference *70*). He also advocates attempting to maintain a vegetative cover on trails by introducing non-indigenous plants and applying fertilizers.

164. Hendee, J. C., R. N. Clark, M. L. Hogans, D. Wood, and R. W. Koch.
1976. Code-A-Site: a system for inventory of dispersed recreational sites in roaded areas, backcountry, and wilderness. USDA For. Serv. Res. Pap. PNW-209, 33 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This paper provides a suggested format for recording data about recreational sites. The system provides an inventory of sites, their resources, recreational opportunities, facilities, and condition. This system, often in revised form, is being widely used by backcountry managers, suggesting that it is a valuable inventory system. (See Schreiner and Moorhead [1976, reference *115*].)

165. Hendee, J. C., G. H. Stankey, and R. C. Lucas.
1978. Wilderness management. USDA For. Serv. Misc. Publ. 1365, 381 p.

This is a textbook, on the principles of wilderness management, written by three social scientists working for the Forest Service. The book includes discussions of the history of the wilderness idea, the legal basis for wilderness, important aspects of wilderness that must be managed, and management approaches. Ecological impacts are treated very generally because of the comprehensive nature of the book. This work provides a good overview of the subject.

166. Huxley, T.
1970. Footpaths in the countryside. Countryside Comm., Scotland. 51 p.

Footpaths are divided into those that develop spontaneously with human use and those that are purposefully constructed. The author relates the development of "natural" footpaths to such factors as human anatomy and motivations. Physical changes on footpaths are described, particularly the elimination of most plant species on paths. In Great Britain, the most resistant plant species, those capable of providing some cover on footpaths, are confined to lower elevations and nonwooded areas. The author discusses in some detail agents which cause footpath erosion, such as water and splash erosion, treading, and creep. He also describes factors to be considered when developing new trails or maintaining existing trails.

167. James, G. A.
1974. Physical site management. *In* Outdoor recreation research: applying the results. p. 67-82. USDA For. Serv. Gen. Tech. Rep. NC-9. North Cent. For. Exp. Stn., St. Paul, Minn.

The author states his concern that managers are not utilizing available information on site management. He feels this is a result of the highly dispersed nature of the information and the fact that most studies are so site specific. Some generalizations from the literature are provided, but most of the article is an annotated reading list.

168. Kuss, F. R., and J. M. Morgan III.
1980. Estimating the physical carrying capacity of recreation areas: a rationale for application of the universal soil loss equation. J. Soil Water Conserv. 35:87-89.

This article proposes using the universal soil loss equation, with several term substitutions, to determine the amount of ground cover that must be maintained on a site in order to avoid "excessive" erosion. This equation is based upon rainfall regimen, inherent soil erodibility, slope conditions, and vegetative cover. While this approach offers some possibilities, it should be used with caution outside of the croplands east of the Rocky Mountains, in which the empirical relationships were developed.

169. Leonard, R. E., and A. M. Whitney.
1977. Trail transect: a method for documenting trail changes. USDA For. Serv. Res. Pap. NE-389, 8 p. Northeast. For. and Exp. Stn., Broomall, Pa.

The amount of trail erosion occurring over time can be determined by periodically measuring the cross-sectional area between the trail surface and a horizontal tape. As described, the method can only be used in forested areas and the transects must be subjectively located. Slight modifications of the technique could make it applicable to other situations. The authors take an easy-to-follow, cookbook approach.

170. Lesko, G. L.
1973. A preliminary site capability rating system for campground use in Alberta. North. For. Res. Cent. Inf. Rep. NOR-X-45, 16 p. Edmonton, Alta.

A tentative system, based on theory, for evaluating the relative ability of different areas to tolerate impacts associated with campsite use. Factors included in the system were: degree days above 42° F, mean annual water deficit, shrub cover, grass cover, depth of rooting, thickness of the Ah soil horizon, thickness of the LHF layers (forest floor), slope, total ground cover, soil texture, and drainage. Soil texture and drainage are considered to be the most important independent variables and are used as weighting factors. This type of system would be extremely valuable in making locational decisions. As the author notes, however, it is a preliminary system which could provide misleading results if applied generally. It has not been field tested.

171. Mackie, D. J.
1965. Site planning to reduce deterioration. Proc. Soc. Am. For. 1965: 33-34.

This paper provides a very brief discussion of how to locate and design trails and campsites, from the perspective of a superintendent of parks and recreation in Wisconsin. Although most applicable to developed recreation areas, some of the suggestions may be applicable in backcountry.

172. McEwen, D., and S. R. Tocher.
1976. Zone management: key to controlling recreational impact in developed campsites. J. For. 74:90-93.

Following a good review of the literature, the authors conclude that recreational impacts are inevitable and rapid. Consequently, site rotation is impractical. Instead managers are urged to take advantage of the tendency for use to concentrate and to confine most impact to "impact zones." By recognizing impact, intersite, and buffer zones and by applying different management techniques to each, the authors feel that campsite impacts can be controlled. Although written with developed campsites specifically in mind, this management strategy could also be applied to the backcountry situation, where impacts are also highly concentrated.

173. Miller, R. W.
1974. Guide for using horses in mountain country. Mont. Wilderness Assoc., Bozeman, Mont. 15 p.

This booklet contains many suggestions about how to reduce the impact of horses in the backcountry. Topics include: preparation for pack trips, selecting a campsite, care of stock in camp, safety, conservation, courtesy, and feed for the horses. One point the author emphasizes is that hobbling is an ecologically sound means of restraining horses, while picketing and staking can cause considerable ecological damage unless great care is used.

174. Montgomery, P. H., and F. C. Edminster.
1966. Use of soil surveys in planning for recreation. *In* Soil surveys and land use planning. p. 104-112. L. J. Bartelli, ed. Soil Sci. Soc. Am. and Am. Soc. Agron.

Soils vary in their ability to support different types of recreational developments. Some of the soil parameters which affect capability are wetness, flooding, slope, rockiness, stoniness, permeability, surface soil texture, and depth to bedrock. Tables of limitations for different types of recreation are provided along with a dicussion of how to use soils information when deciding where to locate facilities. This paper is of limited value to backcountry management, but it does present a potentially useful approach.

175. Parks Canada.
1977. Campground Manual. Eng. Archit. Br., Parks Canada, Ottawa.

This manual describes how to plan, design, construct, and maintain campgrounds. Most attention is given to developed, auto-camping facilities, but many of the suggestions can be applied to backcountry sites. The mapping procedures described are particularly useful. This manual is very practical and well illustrated.

176. Parks Canada.

1978. Trail Manual. Eng. Archit. Br., Parks Canada, Ottawa.

An informative, well-illustrative manual on how to plan, design, build, and maintain trails. The first section discusses factors to consider when planning and designing a trail. This includes functional and esthetic requirements, concern for protecting the environment, trail hardening and structures such as bridges, and campsite location and design. The second section details the planning and design process. Section three provides construction and maintenance guidelines, and section four discusses special considerations for particular trail types. This should be a useful guide.

177. Proudman, R. D.

1977. AMC field guide to trail building and maintenance. Appalachian Mt. Club. 193 p.

A practical handbook on how to design, build, and maintain trails, written by the Appalachian Mountain Club's trail supervisor. Chapter headings are: Designing Trails, Environmental Considerations in Trail Design, Trail Layout, Trail Clearing, Trail Marking, Guidelines for Trail Reconstructions, Erosion Control, Hardening Trails in Wet Areas, and Tools. This handbook is well written and illustrated.

178. Rinehart, R. P., C. C. Hardy, and H. G. Rosenau.

1978. Measuring trail conditions with stereo photography. J. For. 76: 501-503.

Stereo photographs can be used to measure the cross-sectional area of a trail. Periodic remeasurements reveal the amount of trail erosion that has occurred. The authors compare the advantages of this monitoring technique to field measurements, such as those described by Leonard and Whitney (1977, reference *169*).

179. Shaine, B.

1972. Trails in wilderness. The Wild Cascades, June-July. p. 12-24.

Presentation of the author's opinions about how to improve upon current wilderness trail policy. Examples of problem trails in wilderness areas in the Cascade Mountains of Washington are provided. He makes the following recommendations: be more careful about routing trunk trails; conduct more ecological research; restrict use if necessary; keep horses out of alpine meadows and off some trunk trails; restoration should be started; keep trails out of the remaining "true wilderness"; initiate a zoning system; and change policy from use dispersal to concentration and restriction of use.

180. Snyder , A. P.

1966. Wilderness management — a growing challenge. J. For. 64:441-446.

This early appeal for wilderness management contends that top management priorities should be improved trail construction and location and more intensive campsite development. This paper is mostly of historical value.

181. Sumner, L.

1968. A backcountry management evaluation, Sequoia and Kings Canyon National Parks. Unpubl. rep. Natl. Park Serv., Sequoia-Kings Canyon National Park, Calif.

This report reviews changes in meadow condition based on 30 years of observations by various researchers. In most places, the pattern was one of increasing degradation until corrective measures were taken in the early 1960's. These measures included complete prohibitions on grazing, limits on length of stay and number of stock, and seasonal restrictions. Improvement during the 1960's led the author to conclude that the stock problem had been solved and that it was time to look at the impact of backpackers.

182. Tocher, S. R., J. A. Wagar, and J. D. Hunt.

1965. Sound management prevents worn out recreation sites. Parks and Recreation 48(3):151-153.

This is a brief, general discussion of how to prevent excessive impacts on recreational sites. Topics include: interpretation and education, patrolling and law enforcement, distribution of users, rationing, zoning, site hardening, fertilization, irrigation, and site rotation. The authors provide only enough detail to suggest management possibilities.

183. Wagar, J. A.

1961. How to predict which vegetated areas will stand up best under "active" recreation. Am. Recreat. J. 1(7):20-21.

Multiple regression equations were generated following a simulated trampling study in a southeast Michigan recreation area. These equations relate vegetation conditions following trampling to site factors and suggest that durable sites are shaded and have a vegetation cover which is dense and contains a large percentage of grasses and woody vines. These results are highly site specific, although the technique may be useful.

184. Walker, R. I.

1968. Photography as an aid to wilderness resource inventory and analysis. M.S. thesis. Colo. State Univ., Fort Collins. 114 p.

This thesis describes methods of using photography to monitor site impacts. The techniques discussed are panoramic photographs, monoscopic photographs, and stereophotogrammetry. Although largely exploratory in nature, it provides technical information which the manager could apply in developing a photographic monitoring system. The panoramic and monoscopic photographs were judged to provide more consistent and accurate results than the stereophotographic techniques investigated.

REHABILITATION OF IMPACTS

(Also see reference numbers *7, 14, 20, 35, 40, 50, 51, 56, 57, 58, 61, 67, 71, 75, 78, 108, 112, 124, 125, 133, 144, 156, 157, 182, 286, and 293.*)

185. Ahlstrand, G. M.

1973. Microenvironment modification to favor seed germination in disturbed subalpine habitats, Mount Rainier National Park, Washington. Ph.D. diss. Wash. State Univ., Pullman. 68 p.

Seeds of four subalpine species collected in Mount Rainier National Park were germinated under laboratory conditions. Stratification reduced the time required for germination and increased the germination success of *Anemone occidentalis, Aster ledophyllus,* and *Festuca viridula.* Seeds of *Lupinus latifolius* germinated readily without stratification. Exposure to light for longer than 14 hours per day inhibited the germination of *Anemone occidentalis.* High temperatures of 111° F (44° C) reduced germination success of all species. Ballard (1972, reference *287*) has suggested that ground surface tempera-

tures of 120° F (49° C) could be lethal to seeds and seedlings. Field plots with treatments (tilled, tilled and peat mulch added, tilled and covered with plastic) and controls were established in disturbed sites at Tipsoo Lake and Sunrise. Seeds of an introduced grass, *Festuca ovina* var. *duriuscula* were used as a standard to test treatment effects on germination. Germination was best on a plot covered with plastic that received ground moisture throughout the season. Other plastic-covered plots did poorly because of high temperatures and/or low moisture levels. Moisture on these plots declined throughout the season because the plastic prevented entry of water from storms. The tilled and tilled and peat mulch added treatments were second best with about 62 to 65 percent germination. Similarity between these two treatments was attributed to loss of the peat mulch from erosion. Lack of moisture was considered the most important factor inhibiting germination under field conditions.

186. Alderfer, R. H., and F. G. Merkle.

1943. The comparative effects of surface application vs. incorporation of various mulching materials on structure, permeability, runoff, and other soil properties. Soil Sci. Soc. Am. Proc. 8:79-86.

This paper is one of the best available on the effects of different kinds of mulch on soil properties. Plots were subjected to artificial rain after 5 tons/acre (11 200 kg/ha) of the different mulches were applied to the surface or incorporated into the soil. Mulches included charcoal, manure, straw, oak leaves, peat, sawdust, pine needles, grass clippings, sand and gravel, glass wool, complete fertilizer (4-12-8), nitrate of soda, and muriate of potash. In general, mulch on the surface had a more beneficial effect than when it was incorporated into the soil because the surface application protected the soil from raindrop splash. No runoff occurred and moisture content was highest on plots treated surficially with manure, oak leaves, straw, sawdust, or pine needles. Except for manure, incorporation of mulch did not increase the infiltration rate after the soil was saturated. The surface treatment with peat was unsuccessful because the mulch was blown off. This problem with peat blowing or eroding from plots is also noted by Ahlstrand (1973, reference *185*). This paper demonstrates the benefits of placing an organic mulch on the soil surface to protect the soil from raindrops and continued erosion. It was interesting to note that even the inorganic mulches such as sand and gravel afforded some protection to the soil surface.

187. Aldon, E. F.

1978. Endomycorrhizae enhance shrub growth and survival on mine spoils. *In* The reclamation of disturbed arid lands. p. 174-179. R. A. Wright, ed. Univ. New Mexico Press, Albuquerque.

Fourteen important southwestern shrub species were found to form associations with endomycorrhizae under field conditions. *Atriplex canescens* plants inoculated in the greenhouse with *Glomus mosseae* exhibited significantly greater survival and growth after two growing seasons than noninoculated plants. A list of New Mexico plant species known to have mycorrhizal associations is included.

188. Aldon, E. F., D. Cable, and D. Scholl.

1977. Plastic drip irrigation systems for establishing vegetation on steep slopes in arid climates. *In* Proc. 7th Int. Agric. Plastics Cong. [San Diego, Calif.] p. 107-112.

A drip irrigation system using plastic pipes enhanced plant establishment on steep slopes in New Mexico. Three different systems, applying a total of 10 to 23.5 in (26 to 60 cm) of water over a 7-week period, were tested. Increases in plant density as well as erosion from increasing amounts of irrigation water were noted. Drip systems such as these might be temporarily connected to streams as water sources and used in backcountry areas.

189. Aldon, E. F., and H. W. Springfield.

1975. Using paraffin and polyethylene to harvest water for growing shrubs. *In* Proc. Water Harvesting Symp. [Phoenix, Ariz. March 1974]. p. 251-257.

Polyethylene plastic and paraffin were tested as means of artificially harvesting water for transplants. Each material was arranged over an area of 9 ft^2 (0.84 m^2) around a transplant to funnel water toward the stem. The two treatments were effective in harvesting water from small storms, capturing an additional 34 to 40 percent of precipitation when compared to controls. Paraffin was spread over the soil surface as granules or flakes at the rate of 0.5 lb/ft^2 (2 kg/m^2). Similar methods, employing degradable materials, could be suitable for backcountry areas where periodic watering of transplants is impractical.

190. Appel, A. J.

1950. Possible soil restoration on "overgrazed" recreational areas. J. For. 48:368.

The author suggests that approximately 2 in (5 cm) of sawdust be placed on campsites and rototilled in with a high nitrogen fertilizer during the off season. This idea has merit, but other evidence in this review suggests the need for additional treatments such as seeds or transplants.

191. Baumgartner, D. M., and R. Boyd, eds.

1976. Tree planting in the Inland Northwest. Wash. State Univ., Coop. Ext. Serv., Pullman, Wash. 311 p.

This is a conference proceedings containing papers on tree planting for Washington, Oregon, Idaho, Montana, and Wyoming. Titles include: "Biology of Planting," "Choosing Tree Species for Planting," "When to Plant," and "Proper Seed Sources — a Key to Planting Success." Some of the methods presented can be used in backcountry areas with modification.

192. Bayfield, N. G.

1979. Recovery of four montane heath communities on Cairngorm, Scotland, from disturbance by trampling. Biol. Conserv. 15:165-179.

Vegetation damage and recovery following trampling were monitored in four heath communities. A total of 0, 40, 80, 120, and 240 walks were administered, with vegetative parameters being measured after 3 months, 1, 2, and 8 years. The major conclusion was that such studies are difficult to design and interpret. Each individual species and plant community had a distinctive pattern of damage and recovery, with some species not showing any damage until 1 year after trampling. The community which suffered the most initial damage also exhibited the greatest recovery after 8 years. The author suggests that studies attempting to rate vegetation susceptibility to trampling need to be continued past the initial damage stage and should consider both delayed damage and the recovery of individual species as well as entire communities.

193. Beardsley, W. G., and R. B. Herrington.

1971. Economics and management implications of campground irrigation — a case study. USDA For. Serv. Res. Note INT-129, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The cost of installation and maintenance of an irrigation system in the Point Campground of Idaho is described. (See

Herrington and Beardsley [1970, reference *226*] for details of revegation.) Cost of the irrigation system was $0.26 per visitor day in 1969, or $95 per campsite. The closure of the campground on Tuesday nights for irrigation was well received by visitors. Alternatives to closing the campground for watering and better design and construction of the sites to facilitate watering are discussed.

194. Beardsley, W. G., R. B. Herrington, and J. A. Wagar.
1974. Recreation site management: how to rehabilitate a heavily used campground without stopping visitor use. J. For. 72:279-281.

Ground cover vegetation was reestablished and maintained through intensive cultural treatment. Good campground layout and artificial surfacing of heavy-use areas were important to this success. Treatments included a control with grass seed only; water and seed; fertilizer and seed; and water, fertilizer, and seed. Introduced species *Poa pratensis, Festuca ovina* var. *duriuscula, Trifolium repens, Festuca rubra* var. *rhizonomous, Poa trivialis,* and the native *Agropyron saundersii* were seeded in varying amounts. Nitrogen, phospate (P_2O_5), and potassium were applied at 70 to 210 (78 to 235), 14 to 35 (16 to 39), and 7 to 17.5 (8 to 19) lb/acre (kg/ha), respectively. Water was applied by sprinklers at a minimum of 1 in (2.5 cm) per week during the summer. Treatments were continued for 4 years. Fertilizer quantities were determined from soil nutrient analyses. The campground was closed to visitors between 2 p.m. Tuesday and 8 a.m. Wednesday each week for watering. This time was chosen to avoid watering prior to a heavy use period. No complaints were received because another campground was available in the area. Percent of available growing space covered by plants increased from 10 to 80 percent over the 4-year period. The combination of fertilizer, seed, and water was the best treatment, with fertilizer and seed second best. Costs per campsite are given.

195. Beardsley, W. G., and J. A. Wagar.
1971. Vegetation management on a forested recreation site. J. For. 69:728-731.

Water, seed, and fertilizer were used in an attempt to revegetate a northern Utah campground in an aspen and conifer forest. Water was applied in July and August at ½ in (1.2 cm) per week for three seasons. Urea formaldehyde and superphosphate were applied at 120 and 40 lb/acre/year (134 and 49 kg/ha/year), respectively. Species included *Phleum pratense, Dactylis glomerata, Bromus inermis, Poa pratensis, Agropyron intermedium, A. trachycaulum, Alopecurus pratensis,* and *Trifolium* spp. Under aspen, treatments increased plant cover from less than 10 percent to over 60 percent. Under the coniferous cover, no treatment increased plant cover to more than 15 percent. In general, as canopy covered decreased, treatment effectiveness increased. The treatment failure under the coniferous canopy is to be expected with the species listed above. Pasture species such as these cannot be expected to do well in this situation. A different grass adapted to growth under a coniferous canopy, such as *Festuca rubra*, might have yielded better results.

196. Berg, W. A.
1974. Grasses and legumes for revegetation of disturbed subalpine areas. *In* Proc., Revegetation of High-Altitude Disturbed Lands Workshop. p. 32-35. W. A. Berg, J. A. Brown, and R. L. Cuany, eds. Environ. Resour. Cent. Inf. Ser. 10, Colo. State Univ., Fort Collins

This is a discussion of selected introduced and native grasses and legumes that either have proven useful for revegetation or show promise for special circumstances. A brief annotation about reproduction, habitat, and utility of each species is included.

197. Berg, W. A., J. A. Brown, and R. L. Cuany, eds.
1974. Proc., Revegetation of High-Altitude Disturbed Lands Workshop. Environ. Resour. Cent. Inf. Ser. 10, 88 p. Colo. State Univ., Fort Collins.

This is the first of three workshops dealing with revegetation at high elevations. (See also, Zuck and Brown [1976, reference *281*] and Kenny [1978, reference *236*].) Topics include plant breeding, erosion control, species suitability, soils and soil problems, seed mixture, and general cultural practices. Most of the papers give a good overview of the topic of concern. Disturbance types discussed were those caused by pipelines, ski area activities, mines, and highways.

198. Bliss, L. C., and R. W. Wein.
1972. Plant community responses to disturbances in the western Canadian Arctic. Can. J. Bot. 50:1097-1109.

This study examined the effects of disturbances on arctic vegetation in western Canada. The disturbances (oil exploration, fire, and bulldozers) are only partially applicable to backcountry and wilderness areas, but the processes of change and recovery are relevant. One of the major impacts was surface subsidence in areas of high ground ice content, a change that may also result from recreational use. Subsidence was caused by removal of plant cover and all or part of the 2- to 8-in (5- to 20-cm) peat layer. Following fire, surface subsidence occurred in areas of high ground ice content, with recovery of grasses and sedges fastest and mosses and lichens slowest. *Eriophorum vaginatum* seedlings were common during the first 2 years, but survival was low. *Calamagrostis canadensis* and *Arctagrostis latifolia* were pioneers. Where surface subsidence of 1.6 to 6.6 ft (0.5 to 2 m) occurred, some revegetation took place, but there was little indication that immediate reseeding could prevent subsidence from occurring. In dwarf shrub-heath dry meadows and low wet meadows, nitrogen (but not phosphorus) appeared strongly limiting to plant growth. Nitrogen and roots were restricted to the surface organic layers. Surface disturbances to this system, therefore, were thought to have far-reaching effects on plant productivity and growth. *Calamagrostis canadensis, Poa lanata,* and *Arctagrostis latifolia* were noted as pioneers in the MacKenzie River Delta area. *Festuca rubra* and *Descurainia* pioneered drier sites and *Arctophila fulva* and *Eriophorum angustifolium* pioneered wetter sites. In seeding experiments, establishment was better on peats, but sustained growth was better on mineral soil, provided the peats and the mineral soils were kept moist. Fertilizer at 112 lb/acre (100 kg/ha) of nitrogen and phosphate, or phosphate alone, yielded better results than nitrogen alone, showing that phosphorus was limiting to the seedlings of species used. *Festuca rubra, Poa pratensis, P. compressa,* and *Phleum alpinum* did equally well on peats and mineral soil while *Alopecurus pratensis* grew better on mineral soil. Results indicated that seeds should be sown either in early spring as snow melts or in late fall before the first snow.

199. Brown, R. W., R. S. Johnston, B. Richardson, and E. E. Farmer.
1976. Rehabilitation of alpine disturbances: Beartooth

Plateau, Montana. Proc., Revegetation of High-altitude Disturbed Lands Workshop. p. 58-73. R. H. Zuck and L. F. Brown, eds. Environ. Resour. Cent. Inf. Ser. 21, Colo. State Univ., Fort Collins.

This paper describes research on methods of rehabilitating mining and highway disturbances in the alpine zone of the Beartooth Plateau, Mont. Results from seeding experiments showed that native species were more successful than introduced species, that fertilizer applications (15-40-5) at 100 lb/acre (111 kg/ha) were essential to plant establishment, and that additions of organic matter in the forms of peat moss at 2,000 lb/ha (2 240 kg/ha), steer manure at 4,000 lb/acre (4 480 kg/ha), or topsoil enhanced the rate of stand establishment. Fall seeding was recommended to ensure adequate moisture for germination and winter cold treatments for native species. Successfully seeded species included: *Deschampsia caespitosa, Alopecurus pratensis, Poa alpina*, *P. pratensis, Phleum alpinum, P. pratense, Dactylis glomerata, Trisetum spicatum*, *Bromus inermis*, *Carex paysonis, Agropyron intermedium*, *A. scribneri*, *A. trachycaulum,* and *Festuca arundinacea*. Seeds of native species were collected by hand. Transplanting experiments were 100 percent successful with some of the above species and with *Antennaria lanata, Lupinus argenteus, Sibbaldia procumbens,* and *Phyllodoce empetriformis*. Segments of turf that had slid down road cuts were employed for transplanting. This was considered the best method because survival rates were higher and because the transplants produced seed in 1 year. Plants were moved only when dormant. It was suggested that transplanting is particularly suitable for small areas of disturbance (such as backcountry campsites). Large-scale nursery production of native grasses in plastic tubes also appeared feasible. Most of the native colonizing species in the area were grasses and sedges. *Epilobium alpinum* and *Senecio* spp. were exceptions. These last colonized more mesic sites where pH was above 5.0.

200. Brown, R. W., R. S. Johnston, and D. A. Johnson.
1978. Rehabilitation of alpine tundra disturbances. J. Soil Water Conserv. 33:154-160.

This paper discusses the continuation of work on the rehabilitation of alpine disturbances described in Brown and others (1976, reference *199*). Most important is a table of plant species found to be successful for revegetation. The authors summarized their own work and added information available in the literature to compile the list.

201. Campbell, S. E., and G. W. Scotter.
1975. Subalpine revegetation and disturbance studies, Mount Revelstoke National Park. Unpubl. rep., 99 p. Can. Wildl. Serv., Edmonton, Alta.

Provides results of transplant trials using *Luetkea pectinata* and a reexamination of areas experimentally trampled 1 year previously and reported in Landals and Scotter (1974, reference *72*). Remeasurement of the trampling plots showed that the plant community which was destroyed most rapidly by trampling, the *Valeriana sitchensis* community, was also the community that recovered most rapidly; when both deterioration and recovery were considered, the most fragile communities were those dominated by the woody species, *Vaccinium membranaceum* and *Cassiope mertensiana*; the least fragile community was *Carex nigricans*; and there was little difference between the effects of one-time trampling and weekly trampling. Experiments with transplanting *Luetkea pectinata* used various treatments with and without water, fertilizer (8-4-4), and different sized plugs. The only significant differences noted over the 6-week observation period were that watering increased survival on dry, exposed sites and that larger plug sizes (15 to 20 cm^2) increased survival rates slightly. Fertilizer had no effect on survival. A limited experiment also suggested the following as possible species for transplanting: *Anemone occidentalis, Antennaria lanata, Arnica mollis*, *Carex spectabilis, Castilleja rhexifolia*, *Juncus drummondii, Luzula glabrata*, and *Valeriana sitchensis*.

202. Cleary, B. D., R. D. Greaves, and R. K. Hermann, eds.
1978. Regenerating Oregon's forests. Oreg. State Univ. Press, Corvallis. 287 p.

This is a handbook for forest regeneration in Oregon. Many of the principles and methods apply to rehabilitation in general. Chapters include: "Seed Source Selection and Genetics," "Site Preparation," "Seedlings," "Ecological Principles," and "Competing Vegetation."

203. Cook, C. W., R. M. Hyde, and P. L. Sims.
1974. Guidelines for revegetation and stabilization of surface mined areas in the western United States. Range Sci. Dep., Sci. Ser. 16, 73 p. Colo. State Univ., Fort Collins.

This book could serve as a general introduction and guide to rehabilitation by seeding. The mechanized methods described here are not appropriate for backcountry or wilderness areas, but the principles apply. Specific treatments and recommendations are made for the following: Northern Great Plains; desert vegetation; subalpine and alpine vegetation; and sagebrush, juniper, ponderosa pine, mountain brush, and aspen communities. Mulches, season of planting, soil preparation, fertilizers, topsoil, and weed control are discussed. The emphasis is on facilitating reclamation by native species.

204. Cordell, H. K., and G. A. James.
1971. Supplementing vegetation on southern Appalachian recreation sites with small trees and shrubs. J. Soil Water Conserv. 26:235-238.

Tree and shrub seedlings less than 24 in (61 cm) tall were planted prior to construction in a developed campground in the southern Appalachian Mountains in order to test the suitability of supplementing existing vegetation with planted stock. In general, survival was low because of damage from construction activities and competition from native plants. Mortality was correlated with overstory canopy in the sense that light-loving species did poorly under dense canopy and a 40 percent overstory cover reduction was associated with the greatest survival. Recreational use did not seem to have an effect on survival. Planting stock was obtained from a commercial nursery and included the following locally native species: *Rhododendron maximum, Kalmia latifolia*, *Leucothoe catesbaei*, *Rhododendron calendulaceum*, *Cornus stolonifera*, *C. florida*, *Cercis canadensis*, *Oxydendrum arboreum*, *Ilex opaca, Tsuga canadensis,* and *Diospyros virginiana.*

205. Cordell, H. K., G. A. James, and G. L. Tyre.
1974. Grass establishment on developed recreation sites. J. Soil Water Conserv. 29:268-271.

This study tested methods of obtaining a grass turf on campsites before they were opened for public use in Cherokee National Forest, Tenn. Treatments included staggered campground opening dates (1, 2, and 4 years after seeding); overstory canopy reductions of 10, 40, and 70 percent; and seeding with three species of grass, *Festuca rubra* var. *heterophylla*, *F. arundinacea* var. K31, and *Poa pratensis*. Fertilizer (15-15-15)

was applied to all sites at about 75 lb/acre (84 kg/ha) at the start of the study. The major findings were: no benefit was obtained from waiting to open the campgrounds for more than 1 year after seeding and dense overstory canopy severely limited establishment of seeded grasses and native colonizing species. The authors thought that a turf would have been established successfully if 46 lb/acre (15 kg/ha) of a 12-4-8 fertilizer had been applied both fall and spring along with repeated mowing to reduce competition from other species.

206. Cordell, H. K., and D. R. Talhelm.

1969. Planting grass appears impractical for improving deteriorated recreation sites. USDA For. Serv. Res. Note SE-105, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.

Seeds of *Agrostis palustris, Zoysia japonica, Festuca elatior* var. *arundinacea, Cynodon dactylon, Festuca ovina* var. *duriuscula, F. Rubra, Poa pratensis,* and *Agrostis tenuis* were planted in campgrounds of National Forests in Georgia and Tennessee. Seeding was completed in September and survival was evaluated in spring, summer, and fall of the following year. Initial establishment was good, but survival was negligible except in protected areas and fenced control plots. This study provides an example of why site design; management methods, such as "impact pads" around heavy use areas; and perhaps fertilizers and water are needed to enhance success.

207. Czapowskyj, M. M.

1976. Annotated bibliography on the ecology and reclamation of drastically disturbed areas. USDA For. Serv. Gen. Tech. Rep. NE-21, 98 p. Northeast. For. and Exp. Stn., Broomall, Pa.

This bibliography includes 691 citations on mining effects and reclamation, mainly in coal regions. References are indexed by area, disturbance type, author, and subject. Approximately 100 references come under the heading "revegetation."

208. Dalle-Molle, J.

1977. Resource restoration. Unpubl. rep., 19 p. U.S. Dep. Interior, Natl. Park Serv., Mount Rainier Natl. Park, Longmire, Wash.

This is an excellent review of trail and campsite restoration methods used in Mount Rainer National Park. Along with rehabilitation efforts, the most important factor in success was to reduce trampling at the sites. The best method of reducing trampling was determined by repeated observations of visitor-use patterns and by questioning visitors as to why they used a particular route and what alternatives they would accept. Specific rechannelling methods included: blocking areas with logs, rocks, limbs, dirt mounds, and transplanted trees or shrubs and marking snow-covered trails with wands or a light layer of soil. A corrected drainage problem on a trail was sometimes enough to keep people from damaged areas. Success was enhanced when an alternative to a closed route was provided. Transplants have been used successfully as long as plants were less than 18 in (46 cm) tall. The importance of a large root ball and water at the time of transplanting is stressed. Seeding with native species was successful, but no list is provided. Cuttings from *Sorbus* sp. were unsuccessful, but no root hormone was applied.

209. Dittberner, P. L., and G. Bryant.

1978. The use of the Plant Information Network (PIN) in high altitude revegetation. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop. p. 52-74. S. T. Kenny, ed. Environ. Resour. Cent., Inf. Ser. 28. Colo. State Univ., Fort Collins.

This is a description of a computer-based data bank of native and naturalized vascular plants in Colorado, Montana, and Wyoming. Information is organized by plant species and then five major categories: geographic, life cycle, biological, reproduction, and ecological and economic. A large quantity of information, such as suitability for revegetation and elevation, is included. Requests are made by specifying such desired characteristics as high revegetation potential, geographic limits, perennial, and elevation. A list of species fitting the request is returned. This appears to be a very useful tool for people working on revegetation in the Rocky Mountain Region.

210. Doran, C. W.

1952. Adaptability of plants for reseeding high mountain peaks in western Colorado. USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Res. Note 10, 2 p. Fort Collins, Colo.

More than 50 species of native and introduced grasses and legumes are rated in this paper for use in Colorado rangeland seeding. Plots of each species were sown above 9,000 feet and then rated on the basis of survival and vigor after a 5-year period. Several introduced grasses (*Poa pratensis, Agropyron repens, Alopecurus pratensis, Agropyron intermedium, Phleum pratensis,* and *Bromus inermis*) were rated excellent for general suitability.

211. Douglas, G. W.

1974. Revegetation studies at Cascade Pass. Unpubl. rep., 18 p. U.S. Dep. Interior, Natl. Park Serv., North Cascades Natl. Park, Sedro Woolley, Wash.

Transplanting experiments were conducted with *Luetkea pectinata* at a heavily used subalpine backcountry area in North Cascades National Park. This species was thought to be ideal for revegetation work because it reproduced rapidly with runners, had a widespread distribution, was a pioneer species, and grew on a variety of sites. Plugs (8.7 cm in diameter) were moved into disturbed areas from adjacent undisturbed sites. *Luetkea* cover declined the first year and then increased during the next 3 years of the study. Frost heaving and damage caused by mammals killed a large number of plants. Nutrient analysis of foliage suggested that lack of nutrients was not a factor in mortality. Individuals of *Deschampsia atropurpurea, Hieracium gracile,* and *Carex nigricans* that were in some of the *Luetkea* plugs exhibited vigorous growth. Other researchers at Cascade Pass (Miller and Miller [1978, reference *248*] have verified that *Luetkea* is a good species to use in revegetation. They have found, however, that larger plugs (15 cm) and plants started from cuttings give a higher survival rate.

212. Dudeck, A. E., N. P. Swanson, L. N. Mielke, and A. R. Dedrick.

1970. Mulches for grass establishment on fill slopes. Agron. J. 62:810-812.

The effects of 11 mulches on seedling establishment of *Bromus inermis* were tested for 2 different years on road slopes in Nebraska. Materials examined were: wood cellulose fiber, excelsior mat, jute netting, wood chips, prairie hay, fiberglass, and emulsifiable asphalt used by itself and as an anchor for excelsior, wood shavings, bark dust, and corn cobs. Only the jute netting and the excelsior mat treatments resulted in satisfactory seedling emergence. The jute net and excelsior mat were both stapled to the ground surface to prevent erosion underneath and movement of the mulch.

213. Dyrness, C. T.
1975. Grass-legume mixtures for erosion control along forest roads in western Oregon. J. Soil Water Conserv. 30:169-173.

Five different seed mixtures of introduced legumes and grasses were tested on road slopes in western Oregon. All plots received 4,000 lb/acre (4 480 kg/ha) of straw mulch and 400 lb/acre (448 kg/ha) of phosphate fertilizer (16-20-0). Legumes were intended to provide a continuing source of nitrogen to the soil so refertilization would not be required to maintain grass cover. Only one legume species (*Trifolium repens*) survived, however, and refertilization was necessary. Other results included: no plant establishment occurred on slopes receiving mulch and fertilizer alone; even a partial grass cover, established with some mixes, was significant in reducing erosion; and unvegetated control plots eroded for the duration of the study. Successful grass species were: *Lolium multiflorum, Agrostis tenuis,* and *Festuca rubra* var. *commutata*. Bunch-type grasses, such as *Festuca arundinacea* and *Dactylis glomerata,* survived as scattered individuals only. A method of measuring soil erosion using cables is described.

214. Ellison, L.
1949. Establishment of vegetation on depleted subalpine range as influenced by microenvironment. Ecol. Monogr. 19:95-121.

Results from permanent plots and experimental seeding were used to evaluate plant succession patterns under the influence of grazing on the Wasatch Plateau. Emphasis was placed on determining the causes for slow plant establishment in bare areas between existing clumps of vegetation. Studies on permanent plots showed that soil surfaces which were initially bare of perennial vegetation could persist in that condition for many years, and that once overgrazing caused these bare areas, erosion, lack of soil moisture, and soil instability tended to prevent plant establishment. This paper along with Brink (1964, reference *296*) and Brink and others (1967, reference *297*) demonstrate the importance of ameliorating site conditions in order to facilitate revegetation on some subalpine sites.

215. Ettershank, G. N., Z. Elkins, P. F. Santos, and others.
1978. The use of termites and other soil fauna to develop soils on strip mine spoils. USDA For. Serv. Res. Note RM-361, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

This was a laboratory study that used soils from mine spoils to determine if termites could be successfully introduced to benefit soil. Results were varied; some parameters increased (calcium, magnesium, carbonate) and some decreased (percent organic matter, sodium, sulfate). The termites had a beneficial effect on soil structure changing it from blocky to granular. This is an innovative approach to soil rehabilitation that should be examined further.

216. Farmer, E. E., R. W. Brown, B. Z. Richardson, and P. E. Packer.
1974. Revegetation research on the Decker Coal Mine in southeastern Montana. USDA For. Serv. Res. Pap. INT-162, 12 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Topdressing of peat held in place by jute netting, fertilizer (15-40-5), several different seed mixtures, and irrigation were tested as means of revegetating a mine spoil in Montana. Soils were ripped to a depth of 10 in (25.4 cm) and harrowed until no large clods remained at the surface. Fertilizer, seed, and peat were applied at 300, 25.5, and 5,000 lb/acre, (336, 28.5, and 5,600 kg/ha), respectively. The combinations of fertilizer, irrigation, and mulch yielded the greatest dry matter production for all seed mixes. The introduced grasses did better than the native grasses in terms of dry matter, but the study period was only one season. Other studies (Farmer and others [1976, reference *217*] and Brown and others [1976, reference *199*]) suggest that native species may do better in the long run. Exact proportions for seed mixtures are provided.

217. Farmer, E. E., B. Z. Richardson, and R. W. Brown.
1976. Revegetation of acid mining wastes in central Idaho. USDA For. Serv. Res. Pap. INT-178, 17 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Acid mining wastes in central Idaho were given several treatments to help achieve revegetation. A combination of lime, mulch (peat covered with jute netting), an 18-46-0 fertilizer at 435 lb/acre (487 kg/ha), and 8 in (20 cm) of topsoil usually provided the most ground cover. The best seed mixture was thought to be a combination of native and introduced species, because the introduced species did well initially and the native species were expected to take over in time. *Achillea millefolium* was able to survive adverse soil conditions with or without supplemental irrigation. *Deschampsia caespitosa* did well on plots seeded with natives only. *Dactylis glomerata, Phleum pratense,* and *Bromus tectorum* dominated plots of introduced species only after 2 years while *Poa pratensis* was unsuccessful. A native species, *Agropyron spicatum,* germinated, but survival was poor. Detailed results on plant biomass, foliar nutrients and soil conditions are included.

218. Fay, S.
1975. Ground-cover vegetation management at backcountry recreation sites. USDA For. Serv. Res. Note NE-201, 5 p. Northeast. For. and Exp. Stn., Broomall, Pa.

This study tested fencing, fertilization, and liming as possible means of restoring vegetation in a backcountry camp area in the White Mountains, N.H. Fertilizer (5-10-5) and hydrated lime were applied at the rate of 1,000 lb/acre (1 120 kg/ha) each. The combination of all three treatments was most effective, but this resulted in only a 4 to 6 percent increase in vegetative cover after one season. This study was too short to give a good picture of recovery rates, but it shows the necessity of additional treatments such as seeding, transplanting, and tilling the soil.

219. Gates, D. H.
1962. Revegetation of high altitude barren slopes in northern Idaho. J. Range Manage., 15:314-318.

Fertilizer, seeds, and mulch in the form of hay were used as treatments in this study. Results are difficult to interpret, but hay with ripe seeds, mowed near the site, and then used as a mulch provided the best seedling establishment. Seed brought in from other geographic locations did poorly. This demonstrates the importance of using seed for revegetation from the same general area where it is to be used. Material collected from one region and then used in another is often not as well adapted as that collected in the immediate vicinity.

220. Gifford, G. F., D. D. Dwyer, and B. E. Norton.
1972. A bibliography of literature pertinent to mining reclamation in arid and semi-arid environs. Man and the Environment Program, Utah State Univ., Logan. 23 p.

The emphasis of this bibliography is on rehabilitation of mining disturbances such as oil field wastes and slag heaps. Sections on general revegetation, mulches, and road stabilization are included. The authors have provided 312 sources.

221. Gomm, F. B.

1962. Reseeding studies at a small high altitude park in southeastern Montana. Mont. Agric. Exp. Stn., Bozeman, Bull 568. 16 p.

Tests were conducted in a subalpine rangeland area to determine the best soil preparation, seeding method, and species to achieve plant establishment. Results showed the following: plant establishment was the same when seeds were broadcast and drilled, except on plots that were plowed and disked rather than disked only; fertilizer increased growth, but not emergence in a greenhouse study; as intensity of disking increased, existing vegetation decreased and seeded species increased; and *Agropyron trachycaulum, A. smithii, A. cristatum, Bromus carinatus, Dactylis glomerata,* and *Poa pratensis* were fairly successful, but *Alopecurus pratensis* and *Bromus inermis* showed the greatest promise for establishing plant cover.

222. Greller, A. M.

1974. Vegetation of roadcut slopes in the tundra of Rocky Mountain National Park, Colorado. Biol. Conserv. 6:84-93.

Eight roadcut slopes in the alpine tundra of Rocky Mountain National Park were examined. Forty to 50 years after denudation, plant coverage was about one-half that of controls in cushion plant communities. The most important pioneer species were bunchgrasses, particularly *Agropyron scribneri* on south-facing slopes and *Poa fendleriana* on north-facing or late-snow-covered slopes. The process of colonization started with slope stabilization by grasses and proceeded to the filling in of interstitial bare areas by mat forming and cushion plants. Areas remained bare until the surface was stabilized by grasses. Other notable colonizers were: *Trifolium dasyphyllum, Sedum lanceolatum, Festuca brachyphylla, Draba aurea, Poa glauca, Erysimum nivale, Artemisia arctica, Trisetum spicatum, Arenaria fendleri, A. obtusiloba, Cirsium scopulorum, Geum rossii, Luzula spicata, Mertensia viridis,* and *Androsace septentrionallis.* These native colonizers might be useful species in a revegetation program on similar sites.

223. Harrington, H. D.

1946. Results of a seeding experiment at high altitudes in the Rocky Mountain National Park. Ecology 27:375-377.

Plant survival was evaluated on an old roadbed 6 years after it had been seeded and transplanted. Native species which successfully established from seed were: *Phacelia sericea, Deschampsia caespitosa, Heracleum lanatum, Trisetum spicatum, Achillea millefolium* ssp. *lanulosa,* and *Phacelia heterophylla.* Transplants of *Phacelia sericea, Arctostaphylos uva-ursi,* and *Phleum alpinum* had poor success. These results tend to be supported by those of other investigations (for example, Brown and others [1976, reference *199*; 1978, reference *200*]).

224. Heede, B. H.

1978. Designing gully control systems for eroding watersheds. Environ. Manage. 2:509-522.

This work emphasizes identification of gully erosion types and their geomorphologic characteristics. In some cases, erosion could be controlled by establishing vegetation only; in other cases, check dams were required. Guidelines are presented that will aid in determining the appropriate check-dam height. Even though this paper deals with erosion problems that are not related to recreational use, the methods and concepts are probably applicable to backcountry trails with severe erosion.

225. Heidmann, L. J.

1976. Frost heaving of tree seedlings: a literature review of causes and possible control. USDA For. Serv. Gen. Tech. Rep. RM-21, 10 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Mechanisms and occurrence of frost heaving are described in some detail. Natural seedlings less than 1-year old were found to be more susceptible to heaving than larger, transplanted stock. Silt soils were more prone to frost action than clay or sand soils. Several methods of reducing frost heaving were discussed: dispersing the soil with sodium phosphates that reduce pore size; waterproofing the soil to reduce the available water for freezing; using cementing agents to hold the soil together; applying salts that lower the freezing temperature of water in the soil; and changing the radiation balance through shade, mulch, or some type of soil coating. Of these methods, changing the radiation balance appears to be the most feasible for backcountry revegetation projects. Addition of 3,000 lb/acre (3 360 kg/ha) of wheat straw mulch, for example, greatly reduced the number of freeze-thaw cycles and subsequent heaving.

226. Herrington, R. B., and W. G. Beardsley.

1970. Improvement and maintenance of campground vegetation in central Idaho. USDA For. Serv. Res. Pap. INT-87, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Water, fertilizer, and seed were applied as treatments to increase vegetation cover in a developed Idaho campground. Prior to treatment, roads, trails, and the area around picnic tables were surfaced with a gravel-asphalt mixture to help channel visitors and "harden" sites. The seed mixture was composed of equal parts by weight of *Festuca ovina* var. *duriuscula, Poa pratensis, Trifolium repens, Agropyron saundersii* and was applied at the rate of 40 lb/acre (45 kg/ha). Fertilizer was put on four times to total 315, 49, and 24.5 lb/acre (353, 55, and 27 kg/ha) of N, P_2O_5, and K, respectively. Water was applied from sprinklers at the rate of 1.1 to 2.6 in (2.8 to 6.6 cm) per week. After 2 years, the most effective treatment was a combination of seed, fertilizer, and water, which increased plant cover from 10 to 50 percent.

227. Hodder, R. L., and B. W. Sindelar.

1971. Tubelings — a new dryland planting technique for roadside stabilization and beautification. Mont. Agric. Exp. Stn., Res. Rep. 18, 19 p. Mont. State Univ., Bozeman. [From Steen and Berg 1975.]

Plants were grown in deep paper tubes reinforced by plastic mesh sleeves and then transplanted into auger holes. The procedure eliminated the need for irrigation during establishment and enhanced survival of several tree, shrub, and vine species on arid sites. This method sounds like it could be a useful technique, but long-term survival as influenced by the plastic mesh should be checked.

228. Horton, J. S.

1949. Trees and shrubs for erosion control in southern California Mountains. Calif. For. and Range Exp. Stn. and State Calif. Dep. Nat. Resour. 72 p.

This paper discusses species used to control erosion on

road slopes, stream channels, burned areas, landslip scars, and sparsely vegetated areas. On steep slopes, brush wattles were of primary importance in providing mechanical soil stabilization so that vegetative cover could be established. Wattles consisted of cut brush placed in trenches along slope contours. Brush was embedded at least 6 in (15 cm) deep in trenches not more than 5 ft (1.5 m) apart. Stakes driven at least 24 in (61 cm) deep, with 2 in (5 cm) exposed, were placed just below the brush. Water readily entered the soil at brush wattles and, therefore, reduced surface runoff and erosion. Temporary plant cover was established using cereal grains, such as wheat, winter rye, and barley. The grains were followed by tree and shrub planting and additional grass and legume seeds. A table of successful tree and shrub species and their appropriateness for deep or shallow soils and full or partial sun is included.

229. Hull, A. C., Jr.

1943. Hand collection and cleaning of seed of native forage plants. USDA For. Serv., Intermt. For. and Range Exp. Stn., Res. Pap. No. 4, 4 p. Ogden, Utah.

Several methods of collecting native seeds by hand are briefly described. These include: hand stripping, combing, cutting and threshing, and a reel collector. The author discusses in detail the use of two hand paddles covered with rubber matting, but little attention is given to seed cleaning.

230. Hull, A. C., Jr.

1974. Seedling emergence and survival from different seasons and rates of seeding mountain rangelands. J. Range Manage. 27:302-304.

An analysis of factors affecting emergence and survival of seeded grasses on a subalpine range in Idaho is presented in this study. More seedlings emerged with seeding rates of 25 lb/acre (28 kg/ha) then with 10 lb/acre (11.2 kg/ha). Maximum emergence and survival were obtained from June seedings followed closely by July and then November, October, September, and August seedings. Small seedlings were often killed by drought and frost. Species employed in the study were: *Agropyron intermedium, A. trachycaulum, Alopecurus pratensis, Bromus inermis,* and *Phleum pratense*.

231. Isaacson, J. A.

1973. Use of native species on exposed soil sites. Unpubl. rep., 6 p. USDA For. Serv., Coeur d'Alene Nursery, Coeur d'Alene, Idaho.

Native plant species have been germinated and grown at the Coeur d'Alene Nursery and then shipped to other areas for planting. This paper summarizes some of the advantages of using native species and lists quantities of plants produced in 1972. When collecting native seeds, one must know: where to obtain sufficient seed at the proper state of development, when seeds are ripe and for how long they can be collected, and how to collect seed economically. Most seed should be collected from well-ripened fruit, but *Sorbus scopulina, Cornus stolonifera,* and *Acer glabrum* seed must be collected from slightly green fruit to achieve best germination. Some plants, such as *Ceanothus*, have explosive seed dispersal mechanisms and must be watched closely to select the proper time for collection. Planting of nursery stock has been accomplished with an auger for larger, long-rooted seedlings and a mattock or similar tool for smaller individuals. Experiments with direct seeding showed: sowing rates greater than 20 lb/acre were not beneficial; follow up fertilization the next year was essential; native shrubs and forbs did poorly on severe, dry sites; smoothing road slopes after construction had a detrimental effect on seedling establishment; and, once a site had been established with grass cover, native shrubs and forbs could be planted. Native species grown in the nursery from seed are listed. Ammonium phosphate fertilizer (16-20-0) was recommended at 500 lb/acre (560 kg/ha), unless there is a danger of it leaching into water supplies. Under these conditions, 250 lb/acre (280 kg/ha) was suggested. Frequently in rehabilitation work, plants for transplanting are in short supply. One alternative as suggested by Miller and Miller (1976, reference *247,* 1978, reference *248*) is to take cuttings or seeds to a greenhouse for propagation and subsequent transport to the revegetation area. Another alternative is to send seeds to a nursery, such as the one at Coeur d'Alene, where the plants can be grown and then returned to the sender.

232. Johnson, L., and K. Van Cleve.

1976. Revegetation in arctic and subarctic North America: a literature review. Cold Regions Res. and Eng. Lab. 76-15, 32 p. Hanover, N.H.

This review presents a good overview of revegetation and rehabilitation practices and problems in the arctic. Topics include site preparation, native versus introduced species, plant succession, species selection, and results of work on several species that have been used in the region. Native species with good potential for rehabilitation include: *Poa glauca, Festuca rubra*, *Arctagrostis latifolia, Puccinellia borealis, Deschampsia caespitosa*, *D. beringensis,* and *Calamagrostis canadensis* from seed; *Eriophorum vaginatum* from transplants; and *Betula* spp. and *Picea* spp. from cuttings. It was pointed out that the success of seeding was dependent on individual site conditions.

233. Johnston, R. S., R. W. Brown, and J. Cravens.

1975. Acid mine rehabilitation problems at high elevations. *In* Watershed Manage. Symp. p. 66-79. ASCE Irrig. and Drain. Div., Logan, Utah.

This paper presents a synopsis of ecological problems and factors involved in acid mine rehabilitation, but no results are provided because work had just been started at the time the paper was presented. Factors thought to be limiting to plant establishment included high solar radiation, cool air temperature, wind erosion, frost disturbances, short growing seasons, nutrient deficiencies, toxic chemicals, acid soils, and lack of water. Results of similar studies are reported in Farmer and others (1976, reference *217*) and Brown and others (1976, reference *199*; 1978, reference *200*).

234. Jollif, G. D.

1969. Campground site-vegetation relationships. Ph.D. diss. Colo. State Univ., Fort Collins. 139 p.

Some potential revegetation techniques were tested in the most severely deteriorated parts of three campgrounds in Rocky Mountain National Park. Treatments included seeding with three introduced grass species (*Festuca arundinacea, Bromus inermis,* and *Agropyron intermedium*), watering, and fertilization with nitrogen (½ to 1 lb per 1,000 ft^2; 24.4 to 48.8 kg/ha). The combination of seeding and fertilization was highly effective; watering also increased yields under most conditions. The author emphasizes the need to manage each site as individually as possible.

235. Keane, P. A.

1977. Native species for soil conservation in the Alps-New South Wales. J. Soil Conserv. Serv., N.S.W. 33:200-217.

This paper discusses the suitability of some native species for revegetating eroded alpine areas in the Snowy Mountains of Australia. It provides a good example of the type of potentially valuable autecological information that can be collected by studying species which naturally colonize bare areas. Mat-forming plants are the most successful native colonizers. Suggested treatments for increasing survival rates are offered for each growth form discussed.

236. Kenny, S. T., ed.
1978. Proc., Revegetation of High-altitude Disturbed Lands Workshop. Environ. Resour. Cent. Inf. Ser. 28. Colo. State Univ., Fort Collins. 213 p.

This is a collection of papers dealing with revegetation methods and results at high elevations. Topics include: economic and political aspects of revegetation, rare and endangered species, methods of testing soil nutrient status, a plant information network, plant breeding, mycorrhizae, mulches for erosion control, construction methods to make revegetation easier, species for revegetation in Alaska, and mining disturbance projects. A few papers have been reviewed separately.

237. Kidd, W. J., Jr., and H. F. Haupt.
1968. Effects of seedbed treatment on grass establishment on logging roadbeds in central Idaho. USDA For. Serv. Res. Pap. INT-53, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This paper presents the results of a reseeding study using scarification and mulch to establish grass cover on logging roadbeds in *Pinus ponderosa* forests of central Idaho. Scarification treatments resulted in significantly greater seedling establishment than occurred on controls, but only when seeding followed treatment. Loosening the soil to a depth of 12 in (31 cm) compared to 3 in (8 cm) gave only slightly better results. Mulching with a 1-in (2.5-cm) layer of wood chips had a depressing effect on seedling establishment, although this effect was lessened when fertilizer was also added. Fertilizer alone at the rate of 40 lb/acre (45 kg/ha) of nitrogen and phosphorous gave better results than any treatment using mulch. North-aspect roads and sites receiving partial shade from adjacent trees exhibited better seedling establishment than south-facing slopes or full-sun sites. *Bromus inermis, Agropyron intermedium*, and *A. cristatum,* had the highest overall establishment rates (16 to 22 percent survival) and were thought best suited to the conditions of the study area. *Poa bulbosa,* however, was the best species on southwest-facing slopes. *Secale cereale* achieved initial establishment, but disappeared within 2 years.

238. Klock, G. O.
1969. Use of a starter fertilizer for revegetation establishment. Northwest Sci. 43:38. [Abstract only.]

"A successful soil stabilization program to prevent erosion requires the establishment of a vigorous ground cover immediately following site disturbance. The proper use of a starter fertilizer to meet this requirement has been demonstrated in the laboratory and in field investigations on newly developed ski slopes near Wenatchee, Wash. *Agropyron cristatum* was planted in the greenhouse on unfertilized soil from the ski slopes. Seedlings emerged but did not develop once seed energy stores had been exhausted. In 56 days the same soil type, fertilized with a prescription prognosticated by soil chemical analyses, produced up to 1.72 tons/acre (3 853 kg/ha) of ovendry material. Field plots established on ski slopes in August of 1968 confirm the validity of the greenhouse diagnosis."

239. Klock, G. O.
1973. Mission Ridge — A case history of soil disturbance and revegetation of a winter sport development. USDA For. Serv. Res. Note PNW-199, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Lolium perenne and a mixture of *Dactylis glomerata, Phleum pratense,* and *Festuca ovina* var. *duriuscula* were broadcast seeded in the center of a ski run at Mission Ridge, Wash. A starter fertilizer was applied at the rate of 100 lb/acre (112 kg/ha) each of nitrogen (urea), phosphorus (superphosphate), and potassium (muriate of potash). The surface was lightly harrowed to cover seed and to minimize fertilizer loss from volitilization. Plants were successfully established by fall and exhibited good growth the following year. Plots receiving no fertilizer were unsuccessful.

240. Klock, G. O., A. R. Tiedemann, and W. Lopushinsky.
1975. Seeding recommendations for disturbed mountain slopes in north central Washington. USDA For. Serv. Res. Note PNW-244, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Several species of native and introduced grasses and legumes were seeded in different combinations on firelines in north-central Washington. A starter fertilizer (ammonium phosphate sulphate, 16-20-0-15) was applied at 300 lb/acre (336 kg/ha). In general, success decreased with increasing elevation, except for *Poa compressa* which did well at higher elevations. The starter fertilizer was essential for good seedling establishment. Seedling mortality at higher elevations was attributed to frost heaving, cold air, soil temperature, short growing season, and high solar radiation. The most successful species overall were the introduced species: *Dactylis glomerata, Phleum pratense, Lolium perenne, Bromus inermis,* and *Festuca arundinacea.* The authors note that while the use of native species is to be encouraged, their rate of spread is often slow and introduced species may be necessary to establish an initial cover. An extensive table of species cover after 1 and 2 years and of seeding rates is included.

241. McArthur, E. D., B. C. Giunta, and A. P. Plummer.
1974. Shrubs for restoration of depleted ranges and disturbed areas. Utah Sci. 34:28-33.

Shrubs are an important element of the vegetation over much of the arid portions of the West. They provide habitat for wildlife, forage for livestock, and help stabilize soil on disturbed habitats. Some species have a wide ecological tolerance and are particularly valuable for rehabilitation work. More than 30 species are listed in this paper along with the vegetation types where they occur and their suitability for soil stabilization and range restoration. Geographic range and ecological characteristics of the following native shrubs are discussed in some detail: *Cowania mexicana, Falugia paradoxa, Symphoricarpos oreophilus, Kochia prostrata,* and several species of *Artemisia, Atriplex, Chrysothamnus,* and *Purshia.*

242. McClelland, B. R.
1972. Logan Pass seeding experiment. Unpubl. rep., 5 p. U.S. Dep. Interior, Natl. Park Serv., Glacier Natl. Park, West Glacier, Mont.

A series of seeding experiments were conducted in disturbed areas at Logan Pass between 1969 and 1971. Best seed germination was achieved with *Phleum alpinum, Erythronium*

grandiflorum, Luzula glabrata, and *Deschampsia caespitosa.* Introduced species, *Phleum pratense, Thlaspi arvense,* and *Chenopodium album,* invaded some sites and were recommended for removal. Mortality of native species after germination was attributed to lack of moisture and soil erosion. See Hartley (1976, reference *50*) for subsequent observations.

243. McGinnies, W. J., D. F. Hervey, J. A. Downs, and A. C. Everson.
1963. A summary of range grass seeding trials in Colorado. Colo. State Univ., Fort Collins, Agric. Exp. Stn., Tech. Bull. 73, 81 p. [Abstract copied from Steen and Berg 1975, reference *269*.]

"A large number of native and introduced grasses were evaluated for their ability to establish and persist on particular range sites from plains uplands to high mountain grasslands. Species which provided initial establishment, but did not persist could be distinguished. Seed source and ecotype differences were observed. *Bromus inermis, Alopecurus pratensis, Agropyron trachycaulum, Festuca rubra, Phleum pratense, Festuca thurberi,* and *Poa pratensis* were recommended for reseeding."

244. Marchand, P., and E. Spencer
1977. Progress report: Franconia Ridge alpine revegetation study. Appalachian Mt. Club, Boston, Mass. 9 p.

A combination of seed traps, plots on abandoned trails, soil movement measurements, and soil and foliar nutrient analyses were used to determine the best methods and species for rehabilitation of the Appalachian Trail in White Mountain National Forest, N.H. Plants on plots receiving liquid fertilizer (23-19-17) had significantly greater nitrogen and potassium content, but phosphorus content was not affected by fertilization. The soil pH (3.1 to 4.0) was thought to be too low for phosphorus uptake. Native colonizing plants on abandoned trails included mosses, grasses, *Prenanthes* sp., *Arenaria groenlandica, Potentilla tridentata,* and *Juncus trifidus.* Seed traps showed that seed dispersal was limited; *Agrostis borealis* and *Arenaria groenlandica* were the only species collected. Soil movement of up to 0.8 in (2 cm) vertical displacement from frost action was recorded by mid-November. The multiple approaches of this study provide a good example of how ecologically oriented rehabilitation studies can be conducted.

245. Marchand, P., and E. Spencer.
1978. Progress report: Franconia Ridge alpine revegetation study. Appalachian Mt. Club, Boston, Mass. 9 p.

Most of this work describes seed germination, dissemination, and production for selected species along the Appalachian Trail in New Hampshire. *Arenaria groenlandica* and *Juncus trifidus* produced the most seeds and flowers of the four species examined. Only *A. groenlandica, J. trifidus,* and *Potentilla tridentata,* the most important colonizers of abandoned trails, germinated without pretreatment in the laboratory. *Diapensia lapponica, Scirpus caespitosus, Carex bigelowii,* and *Geum peckii* did not germinate. It was noted that seed of colonizing species collected in seed traps rarely traveled more than 1 m from the parent plant. The short travel distance of seeds described in this paper is a contributing factor to the slow recovery of some backcountry disturbed sites, and underscores the importance of adding transplants and seeds to sites where recovery is desired.

246. Megahan, W. F.
1974. Deep-rooted plants for erosion control on granitic road fills in the Idaho batholith. USDA For. Serv. Res. Pap. INT-161, 18 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

This study was started in 1968 and continued through 1972 on road fills in central Idaho. *Pinus ponderosa* (ponderosa pine) was seeded or planted in spacing arrangements of 1.5 × 1.5 ft (0.46 × 0.46 m) or 2.5 × 2.5 ft (0.76 × 0.76 m). Treatments included 1 to 2 in (2.5 to 5.1 cm) of straw mulch held in place with erosion net (galvanized chicken wire), fertilizer (Treefeed Pellets, 28-5-0, 1 per tree), and no mulch or fertilizer. Erosion was measured from catchment trenches lined with plastic. Fertilizer increased planted tree growth an average of 95 percent over 3 years. Planted trees alone provided reductions in erosion from 32 to 51 percent. A grass seeded plot started with 17 plants/ft^2 (183 plants/m^2) and decreased to 1/ft^2 (11/m^2) at the end of the study period. It was noted that the grass seeded plot followed a pattern similar to other road fills the author had observed where initial establishment was fair to good, but cover decreased with time. A 3 to 4 ft (0.9 to 1.2 m) spacing was recommended for future pine plantings.

247. Miller, J. W., and M. M. Miller.
1976. Revegetation in the subalpine zone. Univ. Wash. Arbor. Bull. 39(4):12-16.

This summarizes 7 years of pioneering work on rehabilitation of campsites and trails at Cascade Pass in the subalpine zone of North Cascades National Park. Direct seeding experiments showed that this method was practical only on moist sites. The most successful species were *Carex nigricans* and *Carex spectabilis* followed by *Luetkea pectinata, Potentilla flabellifolia, Saxifraga ferruginea, Valeriana sitchensis,* and *Veratrum viride. Veratrum* required 2 years to germinate. *Arnica latifolia, Lupinus latifolius, Cirsium edula, Erigeron peregrinus* and *Mimulus lewisii* seedings were unsuccessful. Burlap netting laid on top of the plots aided in reducing erosion and maintaining soil moisture. It was necessary to dig the areas up to eliminate compaction. Transplanting was a useful technique, but obtaining material in the area was a problem because of the limited number of places to obtain vegetation without leaving unsightly scars. Clumps that were 5.9 in (15 cm) in diameter had a 97 percent survival rate compared to 50 percent survival with 3.4 in (8.7 cm) plugs. *Carex* spp., *Luetkea pectinata,* and *Potentilla flabellifolia* were successful. Propagation of cuttings and divisions collected near the site to be revegetated and taken to lower elevation nurseries was suggested as the method with the greatest promise. The most difficult problem was logistical since the plants had to be returned to the area in backpacks. *Carex nigricans, Cassiope mertensiana, Luetkea pectinata, Saxifraga ferruginea, Phyllodoce empetriformis, Tsuga mertensiana,* and *Sibbaldia procumbens* had 85 percent survival 2 years after being transplanted at the pass. In the greenhouse, cuttings and divisions were treated with Hormodin 3 (0.8 percent indolebutyric acid) or Rootone No. 10 (0.4 percent Alpha Napthyl acetamide), set in 1:1:1 sand-peat moss-perlite and placed under intermittent mist at 70° F (21° C) soil temperature. See Miller and Miller (1977, reference *249*) for more information on specific methods.

248. Miller, J. W., and M. M. Miller.
1978. Revegetation of impacted subalpine plant communities in North Cascades. Unpubl. rep., 18 p. U.S. Dep. Interior, Natl. Park Serv., North Cascades Natl. Park Complex, Sedro Woolley, Wash.

The revegetation history of Cascade Pass in North Cascades National Park is summarized in this report; some general

guidelines for backcountry revegetation are also included. See Miller and Miller (1976, reference *247*) for most of the results of seeding and transplanting work in in this area. Two guidelines for reducing the impact of revegetation itself include the following advice: when transplanting, fill the holes where plants were removed with soil or rocks to facilitate natural revegetation; and when transplanting wear smooth-soled shoes to minimize trampling damage. Of the species worked with at Cascade Pass, *Luetkea pectinata, Carex nigricans, C. spectabilis,* and *Sibbaldia procumbens* had the greatest survival and growth. *Phleum alpinum,* which exhibited no seed dormancy, was successfully grown from seed in the greenhouse and returned to the pass for planting. A useful table of criteria to determine whether or not a site is suitable for on-site seeding with native species is provided.

249. Miller, M. M., and J. W. Miller.
1977. Suggested revegetation practices. Unpubl. rep., 13 p. U.S. Dep. Interior, Natl. Park Serv., North Cascades Natl. Park, Sedro Woolley, Wash.

This paper discusses species selection, transplanting, seeding, and greenhouse propagation methods. Procedures are described in sufficient detail for the work to be used as a backcountry revegetation manual. Special problems including fire rings, shelter sites, trails, frost heaving, large shrubs, and prevention of additional impact are addressed. This is probably the best paper available on how to rehabilitate backcountry sites damaged as a result of recreational use.

250. Milstein, G. P., and D. Milstein.
1976. Collecting and cleaning of wildflower seed. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 2. p. 41-53. R. H. Zuck and L. F. Brown, eds. Environ. Resour. Cent. Inf. Ser. 21. Colo. State Univ., Fort Collins.

This is an excellent step-by-step guide for collecting wildflower seeds. Information on germination, drying, and storage is also included. A list of species and their germination requirements is included in the index.

251. Mitchell, W. W.
1978. Development of plant materials for revegetation in Alaska. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 3. p. 101-115. S. T. Kenny, ed. Environ. Resour. Cent. Inf. Ser. 28, Colo. State Univ., Fort Collins.

Introduced and native grasses in use or having good potential for revegetation of disturbed sites in Alaska are discussed by species. Cold soils over permafrost and winter survival were noted as important limiting factors that must be overcome for successful revegetation projects. Some Alaska grasses have good potential, but the author indicates that more work is needed to find disease-resistant species or populations.

252. Monsen, S. B.
1975. Selecting plants to rehabilitate disturbed areas. *In* Improved range plants. p. 76-90. R. S. Cambell and C. H. Herbel, eds. Range Symp. Ser. 1, Soc. Range Manage., Denver, Colo.

This is an overview of the different kinds of plants used to rehabilitate disturbed areas. Emphasis is placed on the fact that a wide variety of methods and species may be required to complete a rehabilitation project successfully. The author notes that a combination of grasses, forbs, and shrubs is best to improve forage on range sites, but that planting of shrubs has been discouraged in the past because both planting stock and knowledge of proper planting techniques were lacking. Recent advances in propagating native plants from seeds in nurseries, however, now make it feasible to use more native species, including shrubs (see Isaacson [1973, reference *231*]). A good method of native plant species selection is to use existing plant communities as guidelines. Areas with harsh growing conditions have furnished planting stock for treating severe disturbances. It is also noted that introduced species have proven useful in rehabilitation projects, especially for establishment of an initial plant cover. Native colonizing species that have been successfully transplanted or seeded include: *Penstemon fruticosa, Eriogonum umbellatum, Chrysopsis* spp., *Clematis ligusticifolia, Lonicera ciliosa, Ceanothus martinii, Fallugia paradoxa, Cowania mexicana, Purshia glandulosa, Ephedra viridis, Solidago canadensis, Penstemon* spp., and *Artemisia ludoviciana*. Native seral species that have been successful once established include: *Ceanothus velutinus, Prunus emarginata, Rosa woodsii,* and *Sambucus caerulea*.

253. Moorman, T., and F. B. Reeves.
1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. II. A bioassay to determine the effect of land disturbance on endomycorrhizal populations. Am. J. Bot. 66:14-18.

This is the second part of the study by Reeves and others (1979, reference *261*). *Zea mays* was planted on disturbed and undisturbed sites in Colorado and harvested after 30 days. Inoculum levels of *Glomus fasciculatus* were measured at that time. Two percent of the plants on disturbed soil were infected while 77 percent on the adjacent undisturbed soil were infected. It was suggested that the low levels of active mychorrhizae on the disturbed site will be an important ecological factor in subsequent succession.

254. Packer, P. E., and E. F. Aldon.
1978. Revegetation techniques for dry regions. *In* Proc., Reclamation of Drastically Disturbed Lands. p. 425-450. F. W. Schaller and P. Sutton, eds. Am. Soc. Agron., Madison, Wis.

This is a good overview of revegetation practices and environmental factors in the northern Great Plains and arid Southwest. Soil amendments, mulches, fertilizers, seeding methods, planting methods, and species are discussed for each region. Recent advances in the technology of revegetation and continued management of revegetated areas are also discussed.

255. Palmer, R.
1975. Progress report on trail revegetation studies. Unpubl. rep., 6 p. U.S. Dep. Interior, Natl. Park Serv., Yosemite Natl. Park, Calif.

Test plots, protected by steel fencing and barbed wire, were set up to evaluate rehabilitation success on eight parallel trail scars in Tuolomne Meadows, Yosemite National Park. Techniques tested included combinations of scarification, seeding with *Carex exserta,* burlap mulch, soil addition, sod plug transplanting (mostly *C. exserta*), rock fill, breaking up sod ridges between trails, adding them to the trail, and planting with plugs from the ridges. Observations after 2 years indicate the most effective method was digging perpendicular to the trails and using soil and plugs taken from the ridges between trails as fill.

256. Parsons, D. J., and S. H. DeBenedetti.
1979. Wilderness protection in the High Sierra: effects

of a 15-year closure. *In* Proc. Conf. Sci. Res. in Natl. Parks. p. 1313-1318. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv., Trans. and Proc. Ser. 5. Gov. Print. Off., Wash., D.C.

After a 15-year closure, campsites that had received high visitor use at a subalpine lake were compared to campsites in a continually disturbed lake area and in an undisturbed control site. All areas had similar vegetation, with *Pinus contorta* (lodgepole pine) and *Pinus albicaulis* (whitebark pine) dominating the forest component. Measurements showed that after 15 years, fuel accumulation had not completely recovered, either because of insufficient time or illegal camping. Litter accumulation and soil resistance to penetration on closed sites were comparable to litter accumulation and soil resistance to penetration on controls. Tree mutilation was still evident, but regrowth was occurring. Social trails around the lake were still visible, although there had been some recolonization by *Deschampsia* spp., *Carex* spp., *Vaccinium nivictum, Kalmia polifolia,* and *Aster alpigenus*. This slow recovery of social trails suggests that some means of assisting recovery should be considered.

257. Peterson, E. B., and N. M. Peterson.
1977. Revegetation information applicable to mining sites in northern Canada. Environ. Stud. 3, 405 p. Dep. Indian North. Aff., Ottawa, Can.

An excellent bibliography with detailed annotations. Although it is specifically concerned with northern Canada, many of the papers discuss material that is applicable elsewhere.

258. Plummer, A. P.
1976. Shrubs for the subalpine zone of the Wasatch Plateau. *In* Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 2. p. 33-40. R. H. Zuck and L. F. Brown, eds. Environ. Resour. Cent. Ser. 21, Colo. State Univ., Fort Collins.

Twenty shrub species are rated for their suitability in subalpine revegetation. Ratings were based on seeding success, transplanting success, rate of spread, growth, and adaptation to disturbance. It was suggested that direct seeding be attempted in the fall to overcome the inherent dormancy in most shrub seeds. Transplanting in the spring was thought to be best since sufficient reliable moisture is available at this time. It was noted that successful fall transplanting required both moist soil and an insultating snow cover over winter. Apparently neither is reliable in this region. Other studies show that time of transplanting varies between regions and that the best time should be verified with local growers and foresters. Mechanical seed harvesting methods appeared feasible for some shrubs, but most species were thought to require hand collection. Development of seed orchards at lower elevations was suggested as a possible alternative. Species with particular promise as ground cover and forage were: *Symphoricarpos oreophilus, Chrysothamnus viscidiflorus, Sambucus racemosa,* and two varieties of *Artemisia tridentata*.

259. Plummer, A. P., D. R. Christensen, and S. B. Monsen.
1968. Restoring big game range in Utah. Utah State Dep. Natl. Resour., Div. Fish Game Publ. 68-3, 183 p.

This work summarizes results of research to improve range productivity in Utah. The suitability of more than 400 plant species is reported here. Planting techniques and restoratio principles are discussed in some detail. A useful list of adapted species for each of 12 vegetation types, ranging from pinyon-juniper forests to subalpine herblands, along with ecological characteristics of major species and viability of stored seeds, is included. This is a good reference for rehabilitation in Utah.

260. Ranz, B.
1979. Closing wilderness campsites: visitor use problems and ecological recovery in the Selway-Bitterroot Wilderness, Montana. M.S. thesis. Univ. Mont., Missoula. 125 p.

This study reports on the effects of closing campsites around a popular midelevation (5,865 ft) lake in the Selway-Bitterroot Wilderness, Mont. After 5 years of closure, interesting findings include: closed campsites had 14.7 percent more cover than open campsites; recovery rates suggest that 16 years would be required for return to a "natural" amount of vegetative cover (this is an average figure and assumes a constant rate of recovery); there was no difference in the organic litter cover between open and closed sites, although campsites had 29 percent less litter cover than controls; graminoids, in particular, increased on closed campsites, so that graminoid cover on closed campsites was 50 percent greater than on control plots; most of the prominent increasers on closed campsites were weedy Eurasian species (such as *Poa annua* and *Trifolium repens*); and seven new campsites developed on the lake following the closure of seven campsites. This suggests that vegetation at this location will recover, although it will apparently take 10 to 20 years for a return to "natural" cover values. Recovery of the organic litter layer and original species composition would take much longer. Moreover, with the development of new campsites, the total area disturbed by camping increased greatly. This illustrates some of the reasons why campsite rest-rotation is usually impractical (see Merriam and others [1973, reference *98*]). If selected campsites are closed, alternative sites must be available.

261. Reeves, F. B., D. Wagner, T. Moorman, and J. Kiel.
1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. I. A comparison of incidence of mycorrhizae in severely disturbed vs. natural environments. Am. J. Bot. 66:6-13.

This study compared the incidence of plant species associated with mycorrhizae on an old roadbed with that on an undisturbed area in Colorado sagebrush country. More than 99 percent of the plant cover on the undisturbed community was mycorrhizal while less than 1 percent was mycorrhizal on the old roadbed. The authors cite evidence indicating that many colonizing species are not associated with mycorrhizae while later successional species are. A list of nonmycorrhizal species and genera is included. It is increasingly evident from studies such as this one that mycorrhizae should be of concern to people involved in revegetation. Severely disturbed sites often lack mycorrhizae because mycorrhizal plant species will not survive when transplanted if the soils or plants have not been inoculated (see Zak [1975, reference *348*]). This would be a most important consideration for people trying to recreate a plant community at an advanced stage of succession. Little is known about the mycorrhizal associations of species other than commercial tree species; so obtaining appropriate material for inoculation is not possible at this time.

262. Ripley, T. H.
1965. Rehabilitation of forest recreation sites. Proc. Soc. Am. For. 61:35-36.

This is a general discussion of how to rehabilitate overused recreation sites. Procedures outlined are as follows: determine if the site should be relocated to a more durable place; ensure that all drainage problems have been corrected; establish hardened travel routes that can take heavy use without further damage to vegetation and soils; use shrubs and trees to help divert and channel visitor use onto hardened routes; establish a grass rather than forb turf in the immediate vicinity of such sites as picnic tables; select several tree species to maintain some overstory cover; and provide for continued maintenance of vegetation.

263. Schilling, C. L.
1977. Transplanting sapling-size trees for campground development. J. For. 75:132-135.

A "Tree Spade," a motorized device, was used to transplant trees from 1 to 4 in (2.5 to 10 cm) d.b.h. and 15 to 25 ft (4.6 to 7.6 m) in height. Survival rates are presented for 29 deciduous tree species that were planted in a Kentucky campground. The overall survival rate was 92 percent after 2 years. Saplings are almost impossible to transplant under backcountry conditions with tool limitations, but would be quite useful for rearranging visitor use patterns if a suitable method of transplanting them could be found. Use of the Tree Spade is not appropriate in backcountry areas, but trees could be dug up with the machine in other locations and transported to the backcountry.

264. Schreiner, E.
1977. Evaluation of the 1976 plant restoration project at Lake Constance after one year. Unpubl. rep., 6 p. U.S. Dep. Interior, Natl. Park Serv., Olympic Natl. Park, Port Angeles, Wash.

This report evaluates survival of native plant species 1 year after transplanting in an upper elevation conifer forest of Olympic National Park. Survival ranged from 0 to 80 percent, depending on species. Suggested means of increasing survival were: watering plants before transplanting, adding organic matter to the soil, and pruning foliage to reduce water loss. Such trailing plants and mat-forming plants as *Rubus lasiococcus, Luina hypoleuca, Phlox diffusa,* and *Luetkea pectinata* yielded the best results. Tree seedlings (*Abies lasiocarpa, A. amabilis,* and *Tsuga mertensiana*) over 12 in (30 cm) tall and under 2 in (5.1 cm) tall had very high mortality. Species with less than 40 percent survival included: *Pachistima myrsinites, Phyllodoce empetriformis, Xerophyllum tenax, Rhododendron albiflorum, Vaccinium membranaceum, Cassiope mertensiana,* and *Chamaecyparis nootkatensis.* Some of these species should be tried again under better conditions because the number of transplants was too small (usually one or two). Most of the area was covered with jute netting to hold soil in place and to denote restoration areas to visitors. A table of results and a list of suggested additional species are included.

265. Scott, R. L.
1977. Revegetation studies of a disturbed subalpine community in Olympic National Park, Washington. Unpubl. rep., 62 p. Seattle Pac. Univ., Seattle, Wash.

Treatments of topsoil from an adjacent area and fertilizer pellets (22-8-2) were used on transplants of *Abies amabilis* (Pacific silver fir), *Tsuga mertensiana* (mountain hemlock), *Xerophyllum tenax,* and *Phyllodoce empetriformis.* Transplanting was accomplished in September and all plots were covered with jute netting and watered immediately after planting and several times during the next growing season. No statistical tests were run on the data, but results were interesting: the greatest mortality occurred the winter after transplanting rather than the following summer; fertilizing had no apparent effect on rate of survival, which was 70 percent with fertilization and 72 percent without; south-facing plots exhibited greater mortality than north-facing plots; survival by species was 92 percent for *Phyllodoce,* 83 percent for *Tsuga,* 67 percent for *Abies,* and 4 percent and 69 percent on south- and north-facing slopes, respectively, for *Xerophyllum*; and topsoil had no effect on survival except for a possible increase in *Phyllodoce.* This is a good example of a relatively small-scale revegetation project that can be completed by one or two people in a backcountry area.

266. Scotter, G. W.
1976. Recovery of subalpine meadows under protection after damage by human activities, Yoho National Park. Unpubl. rep., 22 p. Can. Wildl. Serv., Edmonton, Alta.

Rates of recovery for seven untreated exclosures in a subalpine meadow near Lake O'Hara were studied by comparing chart quadrats made 3 years apart. Growth from existing shoot and rootstocks was most rapid although some seedlings became established. Species recovering from rootstocks included: *Antennaria alpina, Vaccinium scoparium, Sibbaldia procumbens, Carex nigricans, Fragaria virginiana,* and *Potentilla nivea.* Seedlings established were: *Arenaria obtusiloba, Sibbaldia procumbens, Epilobium alpinum, Draba crassifolia, Poa* sp., *Poa paucispicula, Agrostis humilis, Juncus drummondii, Ranunculus eschscholtzii,* and *Sagina saginoides.* Plants within exclosures exhibited increased vigor and inflorescence production after 3 years. Based on the reduction per year of bare ground, recovery was quite slow, although different for each type of site. Sites examined included a fire ring, a tent area, bare areas under *Abies lasiocarpa,* trails, and a mixed herbaceous community.

267. Scotter, G. W.
1978. Subalpine revegetation study, Mount Revelstoke National Park. Prog. Note 2. Unpubl. rep., 8 p. Can. Wildl. Serv., Edmonton, Alta.

Transplants of *Luetkea pectinata* and other species reported in Campbell and Scotter (1974, reference *201*) were reexamined 3 years after planting. Water, fertilizer, and topsoil enhanced the survival of *Luetkea,* but success was sometimes high when no treatment was applied. The larger plug size of 15 to 20 cm^2 resulted in the highest survival. It was suggested that the 7 to 10 cm^2 plug size was most economical, however. Of the other species transplanted, *Antennaria lanata, Castilleja rhexifolia, Carex spectabilis,* and *Luzula glabrata* were most successful. These species exhibited good vigor and were setting seed. Species with 25 to 100 percent survival, but only poor-to-fair condition were: *Juncus drummondii, Valeriana sitchensis, Anemone occidentalis,* and *Arnica mollis.* Additional transplants, planted in 1976 by a contract crew, were not surviving well due to frost heaving. The author stressed the importance of moving plants to and from areas with similar ecological conditions.

268. Smith, J. G.
1963. A subalpine grassland seeding trial. J. Range Manage. 16:208-210.

In a seeding trial at 5,700 ft (1 739 m) elevation in central Washington, 14 grasses and eight legumes were planted in June. Legume seed was inoculated with nitrogen-fixing bacteria

and legume plots received broadcast gypsum at 200 lb/acre (224 kg/ha). Half of each grass plot received 200 lb/acre (224 kg/ha) of ammonium sulfate fertilizer. Each species was sown in a monoculture. *Phleum pratense, Agropyron trachycaulum, Elymus glaucus, Poa ampla, Bromus erectus,* and *Agropyron trichophorum* were rated excellent after eight seasons. *Agropyron subsecundum* was the only grass to completely fail. *Astragalus cicer* and three varieties of *Medicago sativa* showed good establishment the first year, but declined rapidly and were present in sparse quantities after 3 years. This lack of success with legumes was also reported by Dyrness (1975, reference *213*). A favorable, but short-lived, response to nitrogen was noted in the grasses.

269. Steen, O., and W. A. Berg.
1975. Bibliography pertinent to disturbance and rehabilitation of alpine and subalpine lands in the southern Rocky Mountains. Environ. Resour. Cent. Inf. Ser. 14, 104 p. Colo. State Univ., Fort Collins.

This is an annotated bibliography with 455 references. Topics include: climate, geology, soils and substrates, native vegetation, disturbance, and rehabilitation. The work provides a good introduction to the literature on the disturbance and rehabilitation of alpine and subalpine ecosystems. Subject and author indexes are provided and material is cross referenced.

270. Stevens, D. R.
1979. Problems of revegetation of alpine tundra. *In* Proc. Conf. Sci. Res. in Natl. Parks. p. 241-245. R. M. Linn, ed. U.S. Dep. Interior, Natl. Park Serv., Trans. Proc. Ser. 5. Gov. Print. Off., Washington, D.C.

This paper provides a good review of what is known about revegetation and factors limiting plant establishment in Rocky Mountain National Park. Transplants established on roadcuts in 1933 have survived, but have not increased in size. The factors considered most important in limiting plant establishment were lack of moisture, high winds, and low nutrient status of soils. Some experiments were conducted on an old building site. Transplanting turf was more successful than adding topsoil, mulches, and snow fences to reduce windspeed. Availability of turf material for transplanting, however, limited the use of this technique. Seedlings of lower elevation introduced species (*Rumex* spp. and *Chenopodium* spp.) were found after the first year. These were probably transported to the site in topsoil. Using topsoil from other locations always involves the risk of bringing in unwanted species, and it may not be possible to eliminate introduced species brought in in this manner.

271. Sundahl, W. E.
1974. Fine cleaning of small seeds by static electricity. Tree Plant. Notes 25(2):2.

Small quantities of seed were cleaned in one plastic and one glass beaker. The plastic beaker was charged with static electricity from wiping with a dry nylon cloth. Chaff and empty seeds tended to cling to the side of the beaker so unwanted material could be wiped out and the process repeated until seed was sufficiently clean.

272. Thalheimer, J. F.
1967. A test of rotated use, watering and seeding for maintaining vegetation under simulated recreational use. M.S. thesis. Utah State Univ., Logan. 51 p.

Understory vegetation under lodgepole pine and aspen, in two campgrounds in northeast Utah, responded favorably to a combination of watering, fertilization, and seeding. Individually none of these treatments had a pronounced effect. Furthermore, herbage production was greatest on sample plots that were used every other week. Where use was continuous or more highly concentrated (all use confined to only 1 week of a 3-week period), production was lower. These results should be treated with caution due to problems with use simulation, the short study period, and questions about its applicability to other vegetation types. Some elements of this study were continued for a longer period of time and were reported in Beardsley and Wagar (1971, reference *195*).

273. Thorud, D. B., and S. S. Frissell.
1969. Soil rejuvenation following artificial compaction in a Minnesota oak stand. Minn. For. Res. Note 208, 4 p.

Sandy loam to loamy sand soils in an undisturbed oak forest in Minnesota were artifically compacted with a gas-powered tamper. Bulk density increased from an initial value of 1.14 g/cm^3 to 1.45 g/cm^3 immediately after compaction. During the 4.5-year study period this decreased to 1.24 g/cm^3. Linear projections suggested that complete recovery would take approximately 6 years. The authors suggest rest-rotation as a management technique for restoring compacted soil. Other investigators suggest, however, that the time required to compact soil from recreational use is much less than the subsequent recovery time (see Merriam and others [1973, reference *98*]).

274. Thorud, D. B., and S. S. Frissell.
1976. Time changes in soil density following compaction under an oak forest. Minn. For. Res. Note 257, 4 p.

Changes in soil density after artificial compaction were examined after 8¾ years. The bulk density of the 0 to 3 in (0 to 7.6 cm) layer had returned to precompaction levels, but the 6 to 9 in (15 to 23 cm) layer exhibited no recovery; bulk density remained at 1.55 g/cm^3 (1.43 for the control). There was no significant change in soil density on control sites during the study period. The results verify the prediction of Thorud and Frissell (1969, reference *273*) that approximately 6 years would be required for the surface soil layer to recover from compaction.

275. Tinus, R. W., and S. E. McDonald.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv. Gen. Tech. Rep. RM-60, 256 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

This is a comprehensive guide to the development and operation of a greenhouse for container-grown tree seedlings. Enough detail is included to help managers decide whether or not to build a greenhouse. Topics include growing media, container types, building design, pest management, tree physiology, growing schedules, hardware, and environmental control. Principles included here apply to greenhouses in general, but the scale of the operation is larger than would be needed for most backcountry rehabilitation projects.

276. Van Horn, J.
1977. Sunrise restoration report, 1977 season. Unpubl. rep., 26 p. U.S. Dep. Interior, Natl. Park Serv., Mount Rainier Natl. Park, Longmire, Wash.

This report summarizes rehabilitation work and observations on restoration projects for the east side of Mount Rainier National Park. Work included erosion control and transplanting of trails and setting up experiments to determine whether a cold

frame was necessary to propagate divisions and cuttings. The most pertinent observations were: visitor education is the best long-term solution to some problems; helicopters were cheaper than backpacking as a means of transporting large quantities of soil to backcountry sites; helicopters for transporting fill help reduce trampling from crews on site, but are noisy; jute netting has probably been used too often and needs to be securely anchored and perhaps buried to a 1-inch depth for best results; and trails can be narrowed through placement of rocks, logs, and transplants (diagrams are provided), but erosion must be controlled if treatments are to be effective. *Festuca rubra*, an introduced grass, was planted in earlier years to establish a quick ground cover on some backcountry sites and many roadcuts. It was thought at the time of seeding that native species would eventually out-compete the fescue and that no viable seed would be produced. Observations by the author indicate that native species have not replaced the fescue in approximately 8 years and that seed is being produced. Viability, however, was unknown at the time of the report. The importance of using native species to maintain the natural integrity of the vegetation is stressed.

277. Wagar, J. A.

1965. Cultural treatment of vegetation on recreation sites. Proc. Soc. Am. For. 61:37-39.

This is a general discussion of how fertilizer, water, mulches, and overstory thinning can be used to increase vegetation on developed campgrounds. Results of the studies mentioned here were only preliminary and are reviewed in detail elsewhere (see Beardsley and Wagar [1973, reference *195*]). Mulch was recommended as a treatment where vigorous tree and shrub growth was desired, but ground cover was not important. Overstory thinning was suggested as a means to increase light intensities, while still providing some shade to help plants recover from trampling damage.

278. Wagner, W. L., W. C. Martin, and E. F. Aldon.

1978. Natural succession on strip-mined lands in northwestern New Mexico. Reclam. Rev. 1:67-73.

Plant species composition and diversity were compared on mined and unmined lands at the McKinley Coal Mine in New Mexico. Mine spoils were between 1 and 13 years old. The vegetation of all mined areas was composed primarily of introduced annuals and a mixture of native and introduced perennials. There were fewer introduced annuals and perennials on unmined sites. After 13 years of recovery, all mined areas were considered to be in a similar phase of early primary succession, suggesting slow natural recovery. Species diversity on mined areas showed no significant relation to the age of the site, although a trend from annuals toward herbaceous perennials was discernible as the time since disturbance increased. It was suggested that native colonizers be seeded to enhance recovery. Recommended native species included: *Atriplex canescens, A. powellii, A. saccaria, A. rosea, Agropyron smithii, Sitanion hystrix, Chrysothamnus nauseosus,* and *C. greenei.*

279. Willard, B. E., and J. W. Marr.

1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. Biol. Conserv. 3:181-190.

Exclosures were established to evaluate recovery of disturbed tundra sites. An area which had been trampled for only 1 year recovered its natural appearance in two seasons. The data presented show no significant increase in cover over the observation period, however. Following the same recovery period, an area which had been trampled for 26 years still showed visible evidence of impact despite increases in cover and species number. An exclosure that reduced, but did not eliminate use, had essentially no effect. Interesting observations included: a species' ability to survive trampling and its ability to recover under protection were not correlated; and seedling survival was greater on exposed B and C horizons than on exposed A horizons. The general conclusion was that almost complete recovery of sites used for only 1 year takes only two growing seasons, while recovery in areas used for longer periods of time may take from several hundred to a thousand years.

280. Young, J. A., R. A. Evans, B. L. Kay, and others.

1978. Collecting, processing, and germinating seeds of Western wildland plants. USDA Sci. and Educ. Admin., Agric. Rev. Man. ARM-W-3, 38 p. Berkeley, Calif.

This is an excellent guide for collecting, storing, and germinating seeds of noncommercial species.

281. Zuck, R. H., and L. F. Brown, eds.

1976. Proc., Revegetation of High-altitude Disturbed Lands Workshop, No. 2. Environ. Resour. Cent. Inf. Ser. 21, 128 p. Colo. State Univ., Fort Collins.

The second of three workshops on high altitude revegetation (see Berg and others [1974, reference *197*], and Kenny [1978, reference *236*]). The papers in this volume contain quite a few details on methods of revegetation that are applicable to backcountry areas. Some of these are: plant establishment, cleaning of seed, special problems with revegetation at higher elevations, seed collection, species suitability ratings, and several reports on specific revegetation projects. Most of the papers deal with high altitude revegetation in general rather than backcountry areas.

RELATED REFERENCES

282. Abbot, H. G., and S. D. Fitch.

1977. Forest nursery practices in the United States. J. For. 75:141-145.

This paper summarizes the general practices of and number of seedlings produced by 99 forest nurseries throughout the United States. The most useful information is a table of chemicals employed to control nursery pests and diseases.

283. Amen, R. D.

1965. Seed dormancy in the alpine rush, *Luzula spicata* L. Ecology 46: 361-364.

This study of *Luzula spicata* seeds from the alpine tundra of the Colorado Front Range revealed complete dormancy due to conditions of the seedcoat. The only effective treatment in breaking dormancy was scarification of the micropylar end of the seed. The duplication of this kind of mechanical action on the seedcoat under natural conditions was thought to be caused by abrasive action of soil particles. Seeds from different locations, collected in different years, did not vary in the extent or degree of dormancy exhibited, nor did they vary significantly in their response to scarification or other treatments. Maximum germination was 90 percent with scarification, and 0 for controls.

284. Amen, R. D.

1966. The extent and role of seed dormancy in alpine plants. Quar. Rev. Biol. 41:271-281.

The mechanisms of seed dormancy were found to be as diverse and frequent in alpine plants as in any other ecological group. Seed germination data from the 62 species suggested that seedcoat inhibition was the most common cause of alpine seed dormancy. Seedcoat inhibition can be alleviated by scarification and may be related to the frequency of abrasive action produced by soil disturbances and wind in the alpine zone. Experimental investigations showed that only a relatively small proportion of alpine species were actually dormant in the seed stage, and that few of these required a cold treatment (stratification) for effective germination. These results differ from those of Mirov (1936, reference *329*) which showed an increasing need for stratification with increasing elevation, although Mirov did not really differentiate alpine species from higher elevation species. Amen also reported that the same species collected at different locations sometimes exhibited different germination requirements.

285. Amen, R. D., and E. K. Bonde.
1964. Dormancy and germination in alpine *Carex* from the Colorado Front Range. Ecology 45:881-884.

The nature of achene dormancy was studied in *Carex albonigra* and *C. ebenea* from the Rollins Pass area of the Colorado Front Range. Germination was determined under treatments of stratification, scarification, leaching, extraction, exposure to light, and application of several plant growth regulators. In *C. albonigra*, only scarification at the basal end of the achenes resulted in germination, while only fluorescent or red light was effective in promoting germination of *C. ebenea*. This light effect was apparently cumulative, with a minimum of about 15 days of continuous light being required.

286. Babb, T. A., and L. C. Bliss.
1974. Effects of physical disturbance on arctic vegetation in the Queen Elizabeth Islands. J. Appl. Ecol. 11:549-562.

The most applicable part of this paper describes recovery of disturbed sites in arctic Canada. On entirely denuded areas, the most rapid reinvaders are the most efficient seed and bulbil producers and, in some places, mosses. Woody perennials and lichens recovered much more slowly. On less disturbed sites, mechanically protected and resistant species recovered most rapidly. In all cases, recovery was extremely slow. Manuring accelerated this recovery but often led to shifts in species composition. Although arctic and alpine vegetations have significant differences, some of these conclusions could also be applied to alpine disturbances.

287. Ballard, T. M.
1972. Subalpine soil temperature regimes in southwestern British Columbia. Arct. and Alp. Res. 4:139-146.

Temperature regimes for bare ground, evergreen shrub, herbaceous meadow, single tree, and tree clump sites are reported in this paper. Diurnal temperature amplitudes are presented for each situation as a percent of the bare ground values. Surface temperatures of 120° F (49° C) were potentially lethal for tree seedlings on the herbaceous meadow sites in early summer. This often-cited paper reveals the extreme temperatures that occur at the soil surface in the subalpine zone. Such extremes are especially probable in disturbed sites. Such sites require amelioration to enhance rehabilitation success with seeds and seedlings.

288. Barnes, K. K., W. M. Carleton, H. M. Taylor, and others, eds.
1971. Compaction of agricultural soils. Monogr., Am. Soc. Agric. Eng., St. Joseph, Mich. 471 p.

This book provides a detailed summary of current knowledge about soil compaction, written by various experts in the field. Some of the topics discussed are the soil compaction process, methods of measuring soil compaction, effects of soil compaction on other soil properties, effects of soil compaction on plant growth, and natural agents which alleviate compaction problems. Although the emphasis is on agricultural soils, some insights can be gained concerning compaction in areas of recreational use.

289. Barton, H., W. G. McCully, H. M. Taylor, and J. E. Box, Jr.
1966. Influence of soil compaction on emergence and first-year growth of seeded grasses. J. Range Manage. 19:118-121.

Grass seeds were sown in plots which received different levels of soil compaction. The number of seedlings which emerged was not affected by compaction. With increasing compaction, however, there were decreases in plant height, pounds of seed, and pounds of forage produced. Roots were unable to penetrate the sandy clay loam soil where bulk density exceeded 1.82 g/cm^3.

290. Bates, G. H.
1950. Track making by man and domestic animals. J. Anim. Ecol. 19:21-28.

This paper discusses differences in the physics of treading by humans and by domestic animals. It notes reasons for the development of permanent footpaths and deviations from this norm. It could be useful in designing paths and evaluating differential impact by humans and packstock.

291. Baver, L. D.
1933. Some soil factors affecting erosion. Agric. Eng. 14(2):51-52.

Early review of soil factors which affect the amount of runoff and the movement of soil by water. Runoff is affected most by the absorptive capacity and permeability of the soil; runoff and (usually) erosion are greater on finely textured soils which are low in organic matter. Ease of dispersion by water and (usually) erosion are also greater on finely textured soils which are low in organic matter. Complications and contradictions to these generalizations are common (for example, Farmer and Van Haveren [1971, reference *305*] and Wischmeier and Mannering [1969, reference *347*]).

292. Bliss, L. C.
1958. Seed germination in arctic and alpine species. Arctic 11:180-188.

This study examined the germination of arctic and alpine plant species under continuous 72° F (22° C) temperatures in petri dishes. One set of seeds for each species was kept in the dark and the other in light. Twenty-two of 36 (61 percent) of the arctic species germinated while 21 of 26 (80 percent) of the alpine species germinated. No great differences were found between the average germination percentages of the various species from the two tundras; 13 of 22 arctic species and 10 of 21 alpine species germinated at the 50 percent level or better. None of the arctic or alpine species germinated exclusively in the dark, but nine of the 43 did so only in the light. All the arctic species tested that were usually found growing on deeply

thawed soil, with the exception of *Salix alaxensis* (fetleaf willow), germinated in both light and darkness. Of those arctic species that most frequently occurred on the wet tundra soils that thawed shallowly, only 48 percent germinated under both light and dark; some with very low percentages. The arctic species are presented separately for the deeply thawed and shallowly thawed soils. All species appear in the index.

293. Blom, C. W. P. M.
1976-1977. Effects of trampling and soil compaction on the occurrence of some *Plantago* species in coastal sand dunes. I. Soil compaction, soil moisture and seedling emergence. Oecol. Plant. 11:225-241. II. Trampling and seedling establishment. Oecol. Plant. 12:363-381.

These experiments examined the emergence and seedling establishment of several species of a noted trampling-resistant genus (*Plantago*) in response to soil compaction and trampling. At optimal soil moisture levels, more emergence occurs on loose soils. At low soil moisture, in the sand dune soils studied, more seedlings emerged on the compacted soils. This was apparently a response to the greater amount of capillary water in the compacted soil, an advantage which overshadowed the negative effect of the soil's greater mechanical resistance. This suggests that compaction in soils with low water-holding capacities is beneficial to some species. Responses to trampling vary considerably among the *Plantago* species, with *P. major* being the most tolerant of trampling stress. A good study of the complex, interacting factors which cause the specific responses to trampling noted in more general studies.

294. Bonde, E. K.
1965. Further studies on the germination of seeds of Colorado alpine plants. Univ. Colo. Stud., Ser. Biol. 18:1-30.

This paper presents the results of seed germination studies on 59 alpine species from the Colorado Front Range. Seeds were stored at room temperature and germinated in the dark. The two tests used involved waiting 3 months and 9 months after collection before germination was attempted.

295. Bonham, C. D.
1972. Vegetation analysis of grazed and ungrazed alpine hairgrass meadows. J. Range Manage. 25:276-279.

By comparing grazed and ungrazed *Deschampsia caespitosa* meadows in Colorado and Wyoming, the author identifies changes in species composition attributable to historic sheep grazing. Similar methods could be used if managers wanted to determine some of the effects of packstock grazing.

296. Brink. V. C.
1964. Plant establishment in the high snowfall alpine and subalpine regions of British Columbia. Ecology 45:431-438.

Reasons for the lack of plant establishment on bare soil adjacent to well-developed vegetation were examined in this study. Lack of establishment was attributed to needle ice, snow slides, and interfacial frost. Soil texture-vegetation interrelationships are discussed with reference to the development of terraces, stone streams, and hummocks. The paper provides insight into factors that need to be controlled before revegetation will be successful at high elevations. No ideas about how to control these processes are given.

297. Brink, V. C., J. Mackay, S. Freyman, and D. G. Pearce.
1967. Needle ice and seedling establishment in southwestern British Columbia. Can. J. Plant Sci. 47:135-139.

In some years, needle ice may occur frequently enough in southwestern British Columbia to cause serious damage to late seedings of sports turf, lawns, and forage. When earlier seeding cannot be undertaken, increased seeding rates to secure dense stands may reduce damage done by needle ice. Needle ice was a factor of considerable potential in the erosion of lightly vegetated or nonvegetated slopes. Damage from the ice occurs when crystals grow, lifting soil particles, seedlings, and duff several centimeters, and then melt. Damaged or dead seedlings, a highly erodible surface, and the movement downslope of a substantial amount of material result. In compacted soils, damage is likely to be greater than in uncompacted soils. Needle ice probably contributes importantly to mortality of plants in rehabilitation projects, even at lower elevations.

298. Chan, F. J., R. W. Harris, A. T. Leiser, and J. L. Paul.
1969. Factors influencing depth of seeding. Tree Plant. Notes 20(2):1-5.

Procedures for determining optimum seeding depth are described in this paper and results are given for the following species: *Prosopis tamarugo* (mesquite), *Eucalyptus vininalis* (eucalyptus), and *Pinus radiata* (Monterey pine). Seed size, soil temperature, and soil texture were shown to be important considerations. *Prosopis,* for example, had best emergence when sown at depths of 0.5 in (13 mm), 0.1 in (3 mm), and 0.4 in (11 mm) for clay, loam, and sand, respectively. A greater seeding depth was required for larger seeds or warmer temperatures. This kind of information can be useful for reseeding projects, but may not be worth obtaining unless extensive seeding is planned.

299. Colorado Mountain Trails Foundation.
[n.d.] Mountain trails: some guidelines on environmental inventory and a selected bibliography. 25 p. Littleton, Colo.

This paper provides 10 guidelines for environmental inventory work associated with trail planning and design. It also contains a very select bibliography (not annotated) on ecology, geology and soils, vegetation, water, wildlife, and recreation. A bibliography, developed by M. J. Liddle, on the ecological effects of recreation is also included.

300. Copes, D. L.
1977. Influence of rooting media on root structures and rooting percentage of Douglas-fir cuttings. Silvae Genet. 26:102-106.

Combinations of perlite, vermiculite, and sphagnum peat were used to determine the best mix for both rooting habit and survival of *Pseudotsuga menziesii* (Douglas-fir) cuttings. Cuttings 2 to 3 in (5.0 to 7.5 cm) long were obtained from 2-to-4-year-old greenhouse seedlings in April and were treated with Captan, an insecticide-fungicide, but no root hormones. Greater proportions of sphagnum peat gave more highly branched root systems while greater proportions of perlite gave relatively poor, short, thick root systems. Sand was associated with long, unbranched roots. Rooting percentages from 68 to 78 percent were obtained from the following, listed from highest to lowest: 1:1 perlite-sand, 1:2 vermiculite-sand, 2:1 vermiculite-perlite, 1:1 vermiculite-sand, 1:2 vermiculite-sphagnum peat. Mixtures with peat tended to become saturated easily, while perlite or

sand mixtures dried out quickly. An optimum mix was suggested as being a compromise between highest rooting percentage and best root structure. This would probably include vermiculite, sand or perlite, and sphagnum peat, perhaps 1:1:1. Miller and Miller (1976, reference *247*) have successfully used a mixture of 1:1:1 sand-peat-perlite.

301. Dahlgreen, A. K., R. A. Ryker, and D. L. Johnson.
1974. Snow cache seedling storage: successful systems. USDA For. Serv. Gen. Tech. Rep. INT-17, 12 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Storing seedlings on site or near the location where they are to be planted allows more freedom in choosing planting times and eliminates the need for expensive storage facilities. This paper describes two different storage systems in some detail, with guidelines for site selection. A cache that is properly constructed can safely provide storage for up to 3 months or more.

302. Donard, G. B., and C. W. Cook.
1970. Carbohydrate reserve content of mountain range plants following defoliation and regrowth. J. Range Manage. 23:15-19.

The carbohydrate reserves of six mountain range plants were measured when plants achieved 10 percent defoliation by clipping. Plants were clipped in early spring and late spring, the times of normal minimum and maximum carbohydrate reserve levels, respectively. *Agropyron inerme, Stipa lettermanii, Symphoricarpos vaccinioides,* and *Geranium fremontii* showed a depletion of total available carbohydrates after defoliation and regrowth. Grass and forb species were affected more by early-spring clipping than late-spring clipping, provided that sufficient regrowth occurred before the onset of fall dormancy. Shrub species seemed to be affected about the same by early- or late-spring clipping. This is one of the few papers that show possible physiological explanations of why plants are extra sensitive to disturbance (trampling) early in the growing season. Hartley (1976, reference *50*) shows that with repeated human trampling, carbohydrate reserves are reduced and plants then have fewer flowers and shorter stature.

303. Edmond, D. B.
1966. The influence of animal treading on pasture growth. Proc. Int. Grassl. Congr. 10:453-458.

This paper summarizes 10 years of work by the author on the effects of experimental sheep trampling in New Zealand. The often dramatic impact of treading (in addition to grazing) on yield and species composition is well illustrated. Impacts were greater on moist than on dry soils.

304. Emerson, W. W., R. D. Bond, and A. R. Dexter, eds.
1978. Modification of soil structure. John Wiley and Sons, New York. 438 p.

This is a compendium of papers dealing with the mechanics of soil structure, its modification by farming, and methods for improvement. The book is aimed at agricultural situations, but some information may prove useful for rehabilitation work since compaction causes a drastic change in soil structure.

305. Farmer, E. E., and B. P. Van Haveren.
1971. Soil erosion by overland flow and raindrop splash on three mountain soils. USDA For. Serv. Res. Pap. INT-100, 14 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The severity of erosional losses is a function of vegetation, soil, precipitation, and topography. A complete vegetation cover is of the utmost importance in minimizing erosion. Where vegetation cover is sparse, the effects of rainfall intensity and topography on amount of erosion are an order of magnitude more important than any soil variable. This suggests that in the area studied, Idaho and Utah, topographic factors are more important criteria in deciding where to locate facilities than soil factors.

306. Federer, C. A., G. H. Tenpas, D. R. Schmidt, and C. B. Tanner.
1961. Pasture soil compaction by animal traffic. Agron. J. 53:53-54.

Plant yield and soil aeration were reduced significantly on sites in Wisconsin grazed by dairy cattle. Penetration resistance and bulk density increased. These changes, attributable to treading, did not intensify after the first year of grazing. This is another example of initial impacts causing most of the observed change. The consequences of grazing by packstock should be generally similar.

307. Forristal, F. F., and S. P. Gessel.
1955. Soil properties related to forest cover type and productivity on the Lee Forest, Snohomish County, Washington. Soil Sci. Soc. Am. Proc. 19:384-389.

The most useful part of this paper provides observations on the maximum bulk density that roots of some tree species can penetrate. This could prove helpful in making species selections for transplanting into compacted soils. Maximum bulk densities (g/cm^3) for tree species were: *Thuja plicata* (western redcedar), 1.8; *Alnus rubra* (red alder), 1.5; *Pseudotsuga menziesii* (Douglas-fir) and *Tsuga heterophylla* (western hemlock), 1.25.

308. Frenkel, R. E.
1970. Ruderal vegetation along some California roadsides. Univ. Calif. Publ. Geogr. 20:1-163.

A thorough discussion of vegetation growing in humanly disturbed areas in California that is most valuable for its summary of information on plants which inhabit frequently trampled areas. The following are common characteristics of these plants: diminutiveness, spreading habit or rosette formation, small leaves, hemicryptophytic or therophytic life form, attenuated lifespan under unfavorable conditions, good nutrient uptake and regeneration, strong and thick cell walls, flexible vegetative parts, ability to spread and reproduce vegetatively, small hard seeds and seeds that germinate after scarification, small flowers, autogamous reproduction, short root to flower distance, short period for reaching seed maturity, large seed production per plant, and seed dispersal by external attachment to animals. Useful for predicting which species will survive trampling and which might be useful in a revegetation attempt.

309. Grime, J. P.
1973. Control of species density in herbaceous vegetation. J. Environ. Manage. 1:151-167.

The author advances the theory that maximum plant species richness (the number of species in a given unit area) occurs at intermediate levels of environmental stress. At these levels, highly competitive species capable of excluding many less competitive species are not widespread, but stress is not so great that only a few species can survive. This suggests that maximum species richness could be expected in areas which receive low levels of trampling stress.

310. Harper, J. L., P. H. Lovell, and K. G. Moore.
1970. The shapes and sizes of seeds. Annu. Rev. Ecol. Syst. 1:327-356.

This is a first-rate review of the adaptive significance of

seed shape and size which is related to the successional role a particular species plays. The paper, while detailed, may provide assistance to people working in revegetation especially where little is known about the species involved; for example, colonizing species often have small seeds and may be recognized by this characteristic. The authors also discuss different mechanisms of seed dormancy. This information will be useful to those attempting seed germination experiments.

311. Harper, J. L., J. T. Williams, and G. R. Sagar.
1965. The behaviour of seeds in soil. I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. J. Ecol. 53:273-286.

Experiments on the effects of soil surface on seed germination of selected species were conducted by compacting the soil or placing different objects, such as glass and small boxes, on the soil surface. The microtopography of the soil surface was also mapped using a 10-point frame. Species used were *Plantago lanceolata, P. major, P. media, Bromus rigidus, B. madritensis, Chenopodium album,* and *Brassica oleracea.* The details of the results are less important than the finding that species responded differently to the varied microenvironments at the soil surface. The authors argue that the availability of suitable microsites on a soil surface offered a means by which the number of plants establishing from seed is regulated and the abundance of some species is determined.

312. Hartmann, H. T., and D. E. Kester.
1975. Plant propagation principles and practice. (3d ed.) Prentice Hall, Engelwood Cliffs, New Jersey. 662 p.

This is an excellent reference manual for anyone involved in propagating plants, from seed or from cuttings.

313. Hatchell, G. E., and C. W. Ralston.
1971. Natural recovery of surface soils disturbed in logging. Tree Plant. Notes 22(2):5-9.

Recovery of soil, that is, the soil's return to normal bulk density values, required about 18 years on the average. Lull (1957, reference *319*) maintains that compaction from trampling is often as severe as compaction from heavy logging equipment.

314. Heidmann, L. J., and D. B. Thorud.
1975. Effect of bulk density on frost heaving of six soils in Arizona. USDA For. Serv. Res. Note RM-293, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Frost heaving increases in severity with increased soil compaction. As frost heaving is a common cause of tree seedling mortality, this could be an important factor, along with trampling, in the absence of tree seedlings on compacted campsites. It also underscores the need to break up compacted soil when attempting revegetation.

315. Hulme, J. K.
[n.d.] Propagation of alpine plants. Alp. Gard. Soc., London. 30 p.

This is a good, easy-to-understand guide on propagation of alpine plants from seed or cuttings. It has plenty of details, but is essentially nontechnical. Examples are provided for species that are difficult to propagate; some of these are included in the index.

316. Johnson, W. M., J. O. Blankenship, and G. R. Brown.
1965. Explorations in the germination of sedges. USDA For. Serv. Res. Note RM-51, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Nine treatments were applied to 27 subalpine and alpine species of *Carex* from Wyoming to determine the best method of achieving germination. The tests were conducted in petri dishes under greenhouse conditions. The following 12 species had germination of 10 percent or less under all tests (highest germination percent in parentheses): *Carex aquatilis* (0), *C. albonigra* (8), *C. athrostachya* (10), *C. kelloggii* (7), *C. lanuginosa* (0), *C. media* (5), *C. physocarpa* (1), *C. praegracilis* (0), *C. pseudoscirpoidea* (0), *C. raynoldsii* (3), *C. rostrata* (0), *C. scopulorum* (2). Species with greater than 65 percent germination and the best method of achieving germination were as follows: *C. ebenea* (tap water leaching); *C. egglestonii* (30-day cold); *C. illota* (control); *C. limnophila* (24-hour cold); *C. microptera* (soil leachate); *C. nelsonii* (soil leachate); and *C. phaeocephala* (24-hour cold). All others species fell between 10 and 65 percent germination; *C. atrata, C. chalciolepis, C. epapillosa, C. hoodii, C. nebraskensis, C. nova, C. petasata,* and *C. tomiei. Carex ebenea* germinated readily under several of the conditions applied in this study, but Amen and Bonde (1964, reference *285*) found the species responded only to red or fluorescent light. It may be that treatment effects in the study by Johnson and others (1965, reference *316*) have been obscured by placing seeds under bright light conditions. They did note that a dark treatment inhibited germination in all species. In most cases, seeds given a 90-day cold treatment germinated less than the controls and always less than seeds given shorter cold treatments.

317. Kozlowski, T. T., ed.
1972. Seed biology. (3 vols.) Academic Press, New York.

This work contains most of the information one might want about seeds. The three volumes cover a range of topics including: metabolism, pathology, germination, longevity, storage, physiology, and collection. A fairly exhaustive list of species with known longevity of seeds is included.

318. Lowdermilk, W. C.
1930. Influence of forest litter on runoff, percolation and erosion. J. For. 28:474-491.

Experiments comparing bare-soil and litter-covered surfaces in California showed dramatic increases in runoff and erosion on bare surfaces. Both of these increases were more pronounced on fine-textured soils. For example, runoff from a bare fine sandy loam was three times the runoff from a similar litter-covered soil, while runoff from a bare clay loam was 16.5 times the runoff from the litter-covered soil. Moreover, differences in amounts of material eroded from bare-soil and litter-covered surfaces were much greater than differences in runoff. This illustrates the importance of maintaining a litter-covered surface.

319. Lull, H. W.
1959. Soil compaction on forest and range lands. USDA For. Serv. Misc. Publ. 768, 33 p. Washington, D.C.

This is a good review of knowledge (as of 1959) about soil compaction and its application to forest and range situations. The author discusses compaction resulting from logging, trampling, and raindrop impact. Other subjects include a discussion of the trampling process, the major independent variables which determine the amount of compaction that occurs, and the effects of soil compaction on soil-water relations and vegetation. Some points of interest were: compaction by raindrops is

significant and may be almost as great on bare ground under a tree canopy as on bare ground in the open; compaction by trampling may be as great as that caused by heavy logging equipment; the soils which have the greatest potential compactibility are medium-textured soils with a wide range in particle size; compaction is more severe when soils are moist and low in organic matter, and when they have low initial densities; compaction increases bulk density, reduces total pore space by the same proportion, reduces noncapillary pore space by a greater amount, and has its greatest effect on infiltration rates; and compaction levels reach a maximum relatively rapidly, beyond which only a great increase in applied force can cause further increases in compaction.

320. Lunt, H. A.
1937. The effects of forest litter removal upon the structure of the mineral soil. J. For. 35:33-36.

The soil properties of an untreated soil sample were compared with those of a soil sample which had its litter cover removed 2.5 years previously. In this short period, the aggregate content and reciprocal of volume weight (bulk density) in the upper inch of the bare soil was reduced to 60 to 65 percent and 81 percent, respectively, of the untreated soil. These changes could easily contribute to increased erosion, illustrating the significance of a litter cover.

321. McDonough, W. T.
1969. Effective treatments for the induction of germination in mountain rangeland species. Northwest Sci. 43:18-22.

Mountain rangeland species examined in this study fell into two groups with regard to seed germination: those that germinated readily with alternating temperatures, and those that required a low temperature treatment after the seeds had imbibed water (stratification). Species in both groups germinated the best when gibberellic acid (GA_3) was added. It was suggested that a cold treatment of seed in water or GA_3 for from 3 to 4 months would be successful for many species if other germination treatments such as scarification, leaching, and exposure to different photoperiods did not work. Species germinating without the cold treatment included: *Achillea millefolium, Agastache urticifolia, Aquilegia coerulea, Arabis glabra, Camelina microcarpa, Chrysothamnus viscidiflorus, Collomia linearis, Grindelia squarrosa, Hesperochloa kingii, Lupinus argenteus, Phleum alpinum, Pedicularis parryi, Penstemon rydbergii, Poa nevadensis, Poa foliosissimum, Potentilla glandulosa, P. gracilis, Rumex crispus, Taraxacum officinale, Thalictrum fendleri,* and *Tragopogon dubius.* Species aided by stratification were: *Actaea glabra, Agoseris glauca, Antennaria rosea, Berberis repens, Bromus polyanthus, Carex hoodii, Cirsium foliosum, Clematis hirsutissima, Descurainia pinnata, Elymus cinereus, E. glaucus, Frasera speciosa, Geranium viscosissimum, Heracleum lanatum, Ligusticum filicinum, L. porteri, Madia glomerata, Sambucus racemosa, Senecio integerrimus,* and *S. serra.* Seeds were collected from the Wasatch and Uinta Mountains of Utah and the Centennial Mountains of Montana.

322. McDonough, W. T.
1969. Seedling growth of ten species of subalpine rangeland in Utah as affected by controlled diurnal temperature alternations. Am. Midl. Nat. 82:276-279.

Seedlings of 10 subalpine rangeland species from Utah were grown in environmental chambers with day temperatures of 68° F (20° C) and night temperatures ranging from 36° to 68° F (2° to 20° C). Cooler night temperatures did not favor growth of these higher elevation species as hypothesized. Eight species exhibited increased growth at higher night temperatures, but no particular night temperature was optimum. *Rumex crispus* and *Aquilegia coerulea* grew best with night temperatures of 59° F (15° C). Other species tested were: *Agastache urticifolia, Geum triflorum, Potentilla glandulosa, Rudbeckia occidentalis, Sibbaldia procumbens, Thalictrum fendleri,* and *Tragopogon dubius.* All species were stored at 36° F (2° C) and apparently germinated successfully without stratification.

323. McDonough, W. T.
1974. Tetrazolium viability, germinability, and seedling growth of old seeds of 36 mountain range plants. USDA For. Serv. Res. Note INT-185, 6 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Seeds of 36 species of mountain range plants, 41 to 44 years old, were tested for viability and germinability. Twenty-nine species gave negative reactions to the tetrazolium seed viability test. Seven species, *Agastache urticifolia, Agoseris glauca, Melica bulbosa, Moldavica parviflora, Stipa columbiana, S. lettermanii,* and *Polemonium foliosissimum,* germinated with some success. The tetrazolium test described in this paper is useful because it allows for a check on viability.

324. Meeuwig, R. O.
1970. Sheet erosion on Intermountain summer ranges. USDA For. Serv. Res. Pap. INT-85, 25 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

In a study utilizing simulated rainfall, plant, litter and, in some cases, stone cover explained most of the variance in amount of soil erosion. Other less significant independent variables were litter weight, slope gradient, and organic matter. This suggests the importance of maintaining a vegetation and litter cover on sites which are potentially erodible.

325. Meeuwig, R. O.
1971. Soil stability on high-elevation rangeland in the Intermountain area. USDA For. Serv. Res. Pap. INT-94, 10 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Soil characteristics which contribute to erodibility were studied in western Idaho and eastern Utah. The most erodible soils were high in clay and low in sand and organic matter. Results are often directly contradictory to Wischmeier and Mannering (1969, reference *347*), illustrating the complex interactions between factors which contribute to erodibility, and the difficulty of extrapolating findings from one area and soil type to another.

326. Megahan, W. F.
1977. Reducing erosional impacts of roads. *In* Guidelines for watershed management. p. 237-261. FAO Conserv. Guide, Food Agric. Organ. U.N., Rome.

This is a summary of existing knowledge, some of which could provide insights when attempting to reduce erosion along trails. Major topics discussed include: erosional processes on roads, road location, road design, and revegetation.

327. Metheny, D., and L. I. Michaud.
1966. Cuttings through the year. (2d ed.) Arbor. Unit Counc. Governing Board, Seattle, Wash. 47 p.

This is a good guide for getting started with small-scale operations in cuttings. Procedures for taking cuttings are presented in a step-by-step outline and a table of the appropriate months for taking cuttings by genus is provided.

328. Minore, D., C. E. Smith, and R. F. Wollard.
1969. Effects of high soil density on seedling root

growth of seven northwestern tree species. USDA For. Serv. Res. Note PNW-112, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This study showed that tree species have differential abilities to grow in compacted soils. The maximum soil bulk density that roots could penetrate was 1.32 g/cm^3 for western redcedar, Sitka spruce, and western hemlock, and 1.45 g/cm^3 for red alder, lodgepole pine, and Douglas-fir. (Compare with Forristall and Gessell [1955, reference *307*].)

329. Mirov, N. T.

1936. Germination behavior of some California plants. Ecology 17:667-672.

Germination behavior of 300 species of California seed plants was examined from an ecological perspective. Four main patterns of germination were observed: seeds that germinated without pretreatment; seeds that required some form of seedcoat rupture (scarification); seeds that needed after-ripening during a cold treatment (stratification); and seeds that required both after-ripening and rupture of the seedcoat. Conifer species germinated fairly well under ordinary greenhouse conditions, but stratification reduced the total germination time. Species in the families Compositae, Gramineae, Labiatae, and Scrophulariaceae germinated well without any pretreatment, while artificial rupture of the seedcoat was necessary for members of the Sterculiaceae, Anacardiaceae, and 16 of 39 species in the Leguminosae. Stratification was required by species in the family Ranunculaceae. A definite pattern between germination behavior and elevation was observed. A greater proportion of the higher elevations species than lower elevation species required stratification for successful germination.

330. Morby, F. E., and R. A. Ryker.

1975. Winter storage and packaging effects on Lucky Peak seedlings. USDA For. Serv. Res. Note INT-195, 10 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The effects of storing tree seedlings in crates or bags at temperatures of 28° F (−2° C) and 33° F (1° C) were examined for five tree species and one shrub species. There was no significant difference in survival or height growth between treatments for spring lifted stock, but the low temperature treatment reduced survival of stock lifted in the fall. The advantage to storing seedlings is that stock can be lifted at different times and held for later distribution. Some nurseries, for example, are unable to lift stock past a certain date because of frozen ground. In addition, lifting stock in the fall rather than spring frees growing space earlier in the year.

331. Nichols, G. E.

1934. The influence of exposure to winter temperatures upon seed germination in various native American plants. Ecology 15:364-373.

This is the only paper we have found that deals with germination of many plant species from the northeastern United States. The germination time and the number of seeds germinating are reported for 141 species collected in New England and Michigan. The author suggests that winter refrigeration of seeds is an important ecological factor in determining the northward distribution of plant species. Approximately 40 percent of the species examined showed increased germination after cold treatments. The period of germination observation was much greater than most studies (to 18 months). All species are included in the index.

332. Nikolaeva, M. G.

1967. Physiology of deep dormancy seeds. Israel Program Sci. Transl. Press, Jerusalem. 219 p. [Available from U.S. Dep. Commerce, Sci. Tech. Inf. Serv., Springfield, Va.]

An excellent detailed source of information on seed dormancy mechanisms and methods of breaking dormancy. It includes specific examples of how to break dormancy in difficult genera, such as *Acer, Sorbus, Crataegus, Fraxinus, Euonymus, Impatiens,* and *Ferula.* Several *Sorbus* species, for example, required from 1 to 4 months of cold stratification followed by up to 9 months of warm moist conditions to germinate successfully. The text is somewhat difficult to follow.

333. Orr, H. K.

1960. Soil porosity and bulk density on grazed and protected Kentucky bluegrass range in the Black Hills. J. Range Manage. 13:80-86.

The effects of grazing and trampling by range cattle were evaluated by examining exclosures which had been established 5 to 17 years previously. Significant decreases in bulk density and increases in macropore space were found in exclosures. Compaction effects were more pronounced and deeper on soils with large silt and clay fractions. Similar effects might be expected following grazing by packstock.

334. Owsten, P. W., and W. I. Stein.

1972. Coating materials protect Douglas-fir and noble fir seedlings against drying conditions. Tree Plant. Notes 23(3):21-23.

Clay slurry, *Xanthum* gum, and sodium alginate protected roots of freshly lifted *Pseudotsuga menziesii (Douglas-fir) and Abies procera* (noble fir) seedlings during 40 minutes of exposure to drying conditions. Control plants, dipped in distilled water, exhibited considerably greater moisture stress. Root coatings such as these should not be put on seedlings destined for storage, but can be useful for transplanting if plants are to be moved some distance. It is essential that roots be protected during transport.

335. Packer, P. E.

1953. Effects of trampling disturbance on watershed condition, runoff, and erosion. J. For. 51:28-31.

Studies of grasslands in Idaho subjected to experimental trampling by a steel "hoof" showed that the amount of trampling an area can receive, before unacceptable levels of erosion occur, is dependent upon the initial amount of cover. Heavy trampling may be tolerable if the ground cover is complete and bare soil openings are small. As total ground cover decreases, less trampling can be tolerated. Similar studies might be useful in setting some capacities on packstock use.

336. Pearcy, R. W., and R. T. Ward.

1972. Phenology and growth of Rocky Mountain populations of *Deschampsia caespitosa.* Ecology 53:1171-1178.

Plants of several populations of *Deschampsia caespitosa* collected in Colorado, northwestern Wyoming, and western Montana were studied for patterns of ecotypic differentiation. Seeds were planted in three essentially similar gardens at elevation of 5,180 ft (1 580 m), 8,984 ft (2 740 m), and 11,705 ft (3 570 m). In each of the gardens, plants from higher elevation sites developed first and had shorter growth periods and less height than plants collected at lower elevations. Survival of all

plants was good, although some mortality after transplanting occurred at the highest elevation garden. Mortality also occurred from a root rot pathogen (*Rhizoctonia* sp.) in the low-elevation garden, particularly with plants from high elevations. A fungicide was effective in eliminating mortality. At the highest elevation garden, only plants from high-elevation sites had mature seeds. This study clearly demonstrates the importance of selecting plants for rehabilitation from similar sites or provinces to ensure success of both transplanting and work with seeds. The difficulties with root rot are noteworthy to people involved with propagating plants in greenhouses.

337. Pelton, J.

1956. A study of seed dormancy in eighteen species of high altitude Colorado plants. Butler Univ. Bot. Stud. 13:74-84.

Seeds collected in the Front Range and Elk Mountains were subjected to a variety of treatments. *Antennaria parvifolia, A. rosea, Cirsium americanum* (partially dormant), *Polygonum viviparum, Senecio mutabilis, Taraxacum officinale,* and *Trisetum spicatum* germinated readily without treatments. Dormant species fell into three categories: those in which dormancy was broken by acid or mechanical scarification (*Androsace septentrionalis, Epilobium halleanum, Galium bifolium,* and *Thlaspi arvense*); those in which dormancy was broken by prolonged stratification under moist cold conditions (*Erythronium grandiflorum* and *Lomatium dissectum*); and those having seeds with complex dormancy mechanisms that could not be germinated (*Saxifraga rhomboidea, Hydrophyllum capitatum, H. fendleri, Mertensia fusiformis,* and *Sambucus microbotrys*). Tests on the latter species included higher germination temperatures, hot water, acid and mechanical scarification, cold stratification, light, and combinations of stratification and scarification.

338. Phipps, H. M.

1974. Growing media affect size of container-grown red pine. USDA For. Serv. Res. Note NC-165, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Pinus resinosa (red pine) seeds were grown in nine different soil media and two types of containers in a greenhouse. Growth differed significantly among the media after 16 weeks, with the largest seedlings produced in a 1:1 peat moss-vermiculite mix. Peat moss-vermiculite had the highest cation exchange capacity (143 meq/100 g) and lowest pH (5.0 to 5.6) of the media tested. The peat-vermiculite mix also retained moisture the longest and seedlings were removed with the least soil disturbance.

339. Sayers, R. L., and R. T. Ward.

1966. Germination responses in alpine species. Bot. Gaz. 127:11-16.

Germination studies were conducted on *Luzula spicata, Deschampsia caespitosa, Geum turbinatum, Pulsatilla ludoviciana, Sedum stenopetalum,* and *Trisetum spicatum. Luzula spicata* did not germinate, although successful germination is reported by Amen (1965, reference *283*). Germination values for most species were consistently high in the alternating temperature range of 50° to 68° F (10° to 20° C) for the low and 77° to 86° F (25° to 30° C) for the high. When the low temperature reached 32° F (0° C) germination was reduced. *Geum turbinatum, Deschampsia caespitosa,* and *Pulsatilla ludoviciana* showed a tendency to germinate better in light rather than dark. *Trisetum spicatum* germinated much better in the dark for the first 2 weeks, but after 4 weeks germination in the dark was less consistently superior. The relationship of plant densities in the field to germination tests is discussed.

340. Smart, A. W., and D. Minore.

1977. Germination of beargrass (*Xerophyllum tenax* (Pursch) Nutt.). Plant Propagator 23(3):13-15.

Xerophyllum tenax seeds collected near Mount Adams, Wash., were given several treatments to induce germination. Unstratified seeds failed to germinate, regardless of other treatments. Following a 24-hour presoak, seeds stratified in vermiculite at 37° F (3° C) for 16 weeks gave germination of 51 to 87 percent. The authors recommended germination temperatures of 64° F (18° C) and 55° F (13° C) for 12-hour days and 12-hour nights, respectively. *Xerophyllum* is an important native subalpine species in the Pacific Northwest. Greenhouse work with this species is now feasible and should aid revegetation work.

341. Steinbrenner, E. C.

1951. Effects of grazing on floristic composition and soil properties of farm woodlands in Southern Wisconsin. J. For. 49:906-910.

Grazed areas had a very different species composition than ungrazed areas. Grazed areas had more invader species, greatly reduced tree reproduction, and decreased organic matter content, air permeability, total pore space, macropore space, and water stable aggregate content. Other than a decrease in available potassium on grazed plots no differences in pH or nutrient content were found. Similar changes could be expected following packstock grazing.

342. Tanner, C. B., and C. P. Mamaril.

1959. Pasture soil compaction by animal traffic. Agron. J. 51:329-331.

Soils on grazed and ungrazed areas in Wisconsin were compared. Grazed areas had decreased air permeability and air capacity (porosity), and increased resistance to penetration and bulk density. Bulk density differences were much less pronounced than differences in the other characteristics. Only a coarse silt loam, with only 10 percent clay, did not change significantly in response to grazing. This has possible application to a better understanding of the impact of packstock on soil properties.

343. Thilenius, J. F.

1975. Alpine range management in the western United States — principles, practices, and problems: the status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

A good review of alpine ecology, climate, and range management. Emphasis is on grazing, species utilization, range conditions and trends, and integrating grazing with concurrent use of land for watersheds, wildlife, recreation, and mining. Little attention is given to restoration, but the summary of alpine ecological processes is useful.

344. Tivy, J.

1973. The concept and determination of carrying capacity of recreational land in the U.S.A. Countryside Comm. Scotland Occas. Pap. 3, 58 p.

This is a review of the concept of carrying capacity written by a visiting geographer from Scotland. It contains definitions of various types of carrying capcity, a discussion of factors which affect carrying capacity, and some examples of how to determine carrying capacity. The second section is an annotated bibliography on carrying capacity and ecological impacts of recreation.

345. United States Department of Agriculture.
1974. Seeds of woody seed plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p. Gov. Print. Off., Washington, D.C.
This book describes life histories, uses, and known germination requirements for many woody seed plants in the United States. This book should not be overlooked as a possible source of information on germinating seeds for revegetation work.

346. Veihmeyer, F. J., and A. H. Hendrickson.
1948. Soil density and root penetration. Soil Sci. 65:487-493.
For a given plant (in this case *Helianthus* sp.), the ability for roots to adequately penetrate compacted soil varied with the texture and moisture content of the soil. This qualifies the results of other researchers, such as Minore and others (1969, reference *328*) where maximum soil bulk densities that species can penetrate without regard to soil texture or moisture were reported.

347. Wischmeier, W. H., and J. V. Mannering.
1969. Relation of soil properties to its erodibility. Proc. Soil Sci. Soc. Am. 33:131-137.
Fifty-five soils from the Corn Belt were subjected to simulated rainfall and the resulting erosion was measured. A soil erodibility equation was developed, involving 22 parameters, which explained 95 percent of the variance. The most highly erodible soils were high in silt, low in clay, and low in organic matter. Particle-size distribution was the most important variable, with erodibility decreasing as silt decreased. Organic matter was also an important factor, tending to decrease the erodibility of most soils. Organic matter increased the erodibility of clay-rich soils, however. One should be cautious about applying these results to soils out of the textural range between silt and sandy loam and to soils which have been compacted at the surface.

348. Zak, B.
1975. Mycorrhizae and container seedlings. *In* Proc. 23d Annu. West. Int. For. Dis. Work Conf. p. 21-23.
The author points out that seedlings grown in containers may not survive, especially in sterile sites like mine spoils, if they have not been inoculated with mycorrhizae in the nursery. Difficulties with selecting the appropriate inoculations are discussed. The implication for rehabilitation work is that survival may be enhanced if plants can be properly inoculated.

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1979. Trampling and erosion in alpine country. J. Soil Conserv. Serv., N.S.W. 35(1):7-12.

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1977. Effects of visitor use on soil and vegetation of campground areas. M.S. thesis. Ohio State Univ., Columbus.
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Species Index for Rehabilitation Citations

The species index is arranged alphabetically by the scientific names used by the authors. Where nomenclature has changed, the currently accepted name is cross-referenced to the name used by the author. We have included an asterick (*) after species not native to the United States and upper-case letters to denote trees (T), shrubs (S), forbs (F), graminoids (G), cacti (C), and legumes (L). The numerals refer to the rehabilitation references that discuss the plant and are followed by lower-case letters in parentheses that indicate the kind of information included in the reference, where c = plant is a colonizing species; g = plant grown under greenhouse conditions; l = seeds given a laboratory germination test; p = number of pounds per acre is provided; r = recovery following human impact assessed; s = field seeding experiment; t = transplanting experiment; and u = utility for rehabilitation evaluated (usually for rangelands).

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Cole, David N., and Edward G. S. Schreiner, Compilers
1981. Impacts of backcountry recreation: site management and rehabilitation — an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-121, 58 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Over 300 references on recreational impacts, impact management, and rehabilitation of impacted sites are briefly reviewed. Their implications for backcountry management are assessed. References are indexed by location, subject, and plant species used for rehabilitation.

KEYWORDS: bibliography, backcountry management, recreational impact, site rehabilitation

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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